AN INEXPENSIVE VARIABLE-AREA FLOWMETER WITH STRAIGHT WALLED GLASS TUBE

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BY
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CERTIFICATE

This is to certify that this work has been carried out under my supervision and has not been submitted elsewhere for a degree.

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Subodh C. Misra

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NOMENCLATURE

A1	Top diameter of the tapered rod, inches
C1	Bottom diameter of the tapered rod, inches
D	Internal diameter of the glass tube
D1	Internal diameter of the float, inches
D2	Orifice diameter of the float, inches
D3	Diameter of the tapered rod at a particular height of float, inches
H1	Height of the float, inches
H2	Length of the tapered rod, cms.
H3	Orifice height of the float, inches
H4	Length of the pipe support, cms.
HT	Float reading at a particular height, cms.
Q	Volumetric flow rate in cc/sec
R	Drag force
ρ_s	Density of the float, gm/cc
ρ	Density of fluid, gm/cc
ρ_w	Density of water, gm/cc
P_1	Pressure at float-top
P_2	Pressure at float bottom
ΔP	Pressure drop due to float
$\Delta P'$	Pressure drop in the flowing liquid
U	Viscosity of water, gm/cc-sec.
VS	Volume of float, cc.
WS	Mass of float, gms
θ	Taper angle of rod, degrees

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ABSTRACT

An inexpensive and simply constructed visual flowmeter has been designed. It consists of a constant cross-section glass tube in conjunction with a tapered rod and a float. The variable area is provided by the annular region between the tapered rod and the glass tube. The liquid flows through the float. Thus, this flowmeter is also capable of measuring flow rates of opaque and translucent liquids. It has a linear calibration curve.

Following experiments with water formulae relating the variables of the meter in the form of dimensionless groups have been developed. These can be used to specify the dimensions of the meter for a given duty.

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CHAPTER I

INTRODUCTION

The measurement of incompressible fluid-flow is often made with the help of variable-area flowmeters. Of these, the rotameter is the most commonly used in industry. The precision needed in industry is quite adequately covered by a rotameter; besides, its other advantages are ease of handling, direct readability and an easy access for cleaning purposes.

Presently in India, rotameters have a high initial cost and even subsequent replacement of the glass tapered-tube is not cheap. This together with the difficulties encountered in reproducing the taper on the glass tubes, and hence duplication of calibration, limits the desirability of this type of flowmeter.

The aim of this study is to explore the possibility of replacing the tapered tube with one having a constant cross-section. A concentric tapered rod fixed at the centre of this tube would provide the variable area for the flow measurement. A float concentric with this central tapered-rod, would slide along the inside of the glass tube. It is estimated that such a flowmeter can be manufactured with ease and at low cost because of the fact that the highly sophisticated and expensive process of manufacturing tapered glass tubes has been eliminated. Moreover, replacement costs of constant cross-section tubes for

this flowmeter will be nominal, and duplication of calibration also simple.

Experimental observations were made in order to establish expressions relating the parameters that affect the performance of the flowmeter and to test the feasibility of operation. The method of dimensional analysis was chosen, from among the various methods, because it helps in producing dimensionless groups, which are in themselves lesser in number than the existing variables. Furthermore, it also enables to obtain dynamically similar systems, which are needed for scale-up processes. This method does not in itself provide a complete solution, rather it yields functional relations which become explicit after combining with appropriate experimental data. These equations, can then explain the effect of various quantities upon the performance of the meter.

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CHAPTER II

LITERATURE REVIEW

The variable area flowmeter was first invented by Edmund Augustine Chemeroy of Paris in 1868. He used a tapered pipe and a float having mechanical transmission to read the flow-rate. Later on, it was repatented several times in different countries between the years 1880 and 1905.

In England, Deacon got a patent in 1875 for a cone-and-disk type flowmeter. Then Alfred Ewing in 1879 for the first time, used a tapered glass tube for measuring liquid flow-rates. George Joslin, obtained in the same year a patent for measuring gas flow rates.

Clausolles, of France, in 1903, found a velocity meter designed to measure velocity of a liquid flowing in a pipe, using a tapered tube and a float.

Karl Kupper was the first to use the word rotameter for variable area flowmeter in 1908 because of the rotary motion of the float resulting from the inclined slots made on its body. Since then this name has been retained for this instrument inspite of the various changes it has undergone till now.

In 1934, Bentzel used a Darcy type tube, one part of which was tapered, and the float indicated the water velocity in the stream according to the rating of the instrument. An excellent review of the historical development of variable

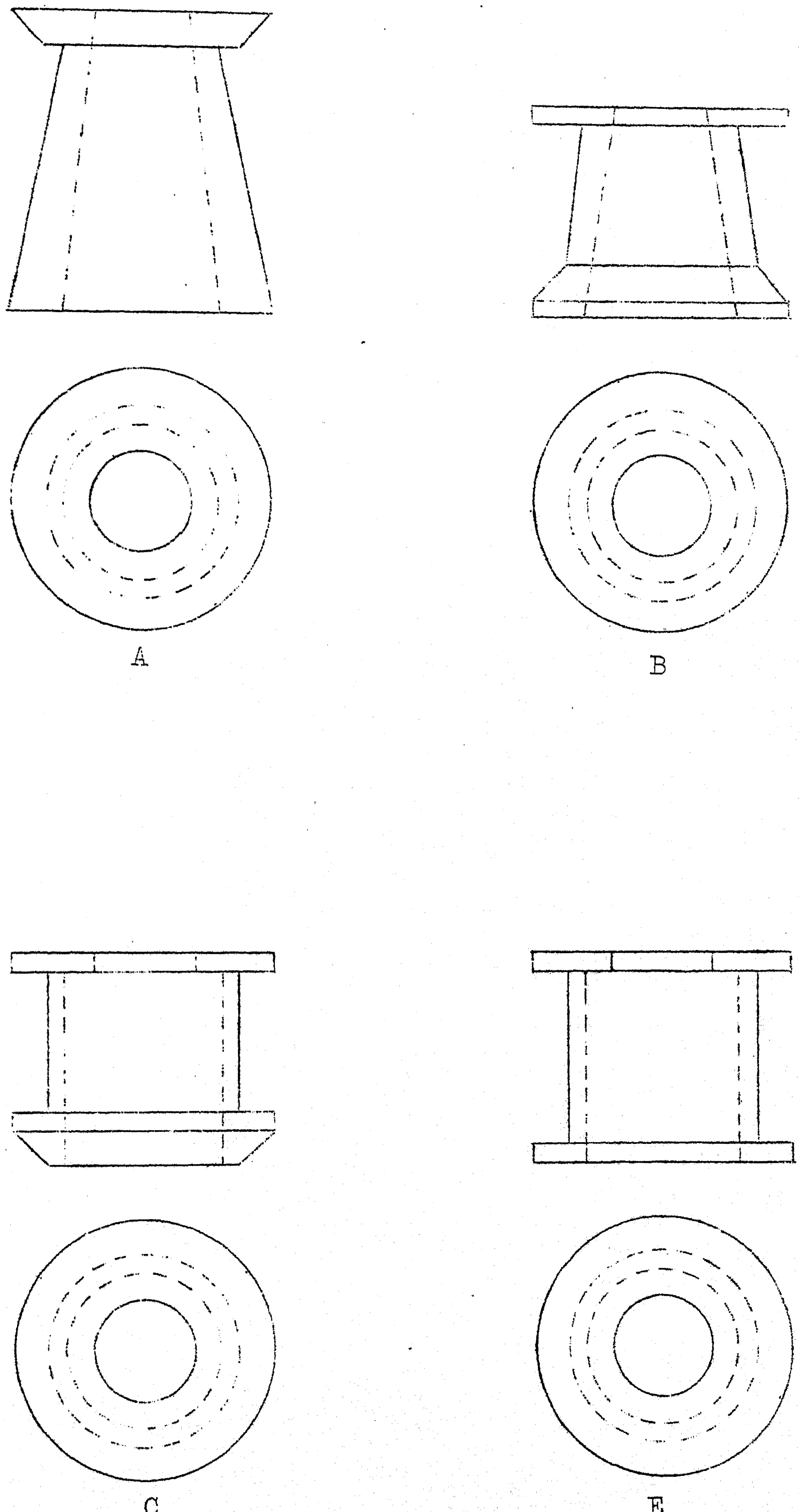

FIGURE 1: TYPES OF BOBS USED BY STOUT AND ROWE

area flowmeters during 1868-1934 is given by Kolupaila.[1]

Stout and Rowe[2] constructed a flowmeter in 1938, consisting of an ordinary glass tube, a metal cone and an annular bob. They studied the effect of shape of the bobs shown in Figure 1, specific gravity of bob, taper of the cone and the changes in the annular area between the bob and the cone. Nearly in all the cases mathematical relationships were not obtained.

Fischer[3] in 1940, designed a float which eliminated the effect of small changes in viscosity on the rotameter calibration. Hence he called it a stable-vis float. This float consisted of a disc having a sharp-edge orifice, which served as a means of flow restriction. A separate body located in a pocket of stagnant liquid, attached to the disc through a tube of small diameter, helped in giving the necessary weight to it. This body, completely removed from the fluid flow stream, did not provide extra drag. A central guide wire was used to guide this float.

Kitner[4] in 1942, developed a visual flowmeter having straight walled tubes. The glass tube had a concentric inner brass pipe which also constituted the inlet and outlet of the flowmeter. Two parallel-sided slots were cut along the 180° axis of the brass pipe. Above but connected with the slots, a number of holes were cut through the pipe walls to allow the fluid to return to the pipe after passing around the float.

The outer glass tube helped in confining the flow as well as enabled to read the float reading with reference to a scale inscribed on the slotted brass pipe. Parabolic calibration profiles were obtained for different cases.

Coleman[5] showed that by making float density twice the mean fluid density, compensation for changes in the fluid density could be obtained.

Danckwerts[6] designed another constant cross-section variable area flowmeter in 1961. He used two concentric transparent tubes, the inner one being made of perspex and perforated by a regular array of holes. A rotameter-type bob was fitted closely inside the perforated tube, as a result of which most of the fluid passed out of the holes below it. The minimum flow which could be measured was that which leaked past the bob. The height of the bob indicated the flow-rate. The biggest disadvantage of this flowmeter was that the flow-rate did not have a linear relationship with float height.

Kehat[7] extended the work of Danckwerts in 1964, to get a linear calibration curve. He replaced the perforated inner tube of Danckwerts with a brass tube having two parallel longitudinal slits, in which the float was allowed to move. The upper end of the inner tube was kept open as that in Danckwerts case. He was successful in getting a linear calibration curve for a small range only.

Kehat's flowmeter was further modified by Kuloor[8] to

get a still better performance. The only modification he did, was to close the outer end of the inner tube by a cap. Thus, the fluid was permitted to flow only through the slit. The results obtained were encouraging. Linear relationships upto 10 cm. float height for all combinations of liquids and float weights were obtained whereas Kehat's flowmeter for the same dimensions would have given linear readings only upto 2 cm. of float height.

In 1965, Tarish[9] produced a highly sensitive rotameter by using a convergent-divergent tube with two floats, one in each tube joined together through a thin rod.

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CHAPTER III

EQUIPMENT DESIGN AND EXPERIMENTAL PROCEDURE

3.1. Equipment Design:

The flowmeter consists of three main components, a glass tube, a concentric inner rod and an annular float. A circular metallic plate was attached to both ends of the rod which served the purpose of keeping it concentric with the glass tube. This in turn was made to rest on a support made out of a thin pipe. For the present work, rubber corks, having inlet and outlet pipes fitted in the centre were fixed at both ends of the glass tube. These also helped in keeping the assembly in position. Figure 2 shows the details of this flowmeter.

Glass Tube: A glass tube having a constant internal diameter of 0.985 inches was employed throughout the experiments. Its length had to be varied according to the total height of the internal assembly of the flowmeter.

Tapered Rod: Several tapered rods shown in Fig. 3a, made out of aluminium, were used in this work. The length (H2), top and bottom diameters, (A1 and C1) and the taper angle (θ) were varied to study their effects on the performance of the meter. Details of the dimensions of the rods used are given in Table I.

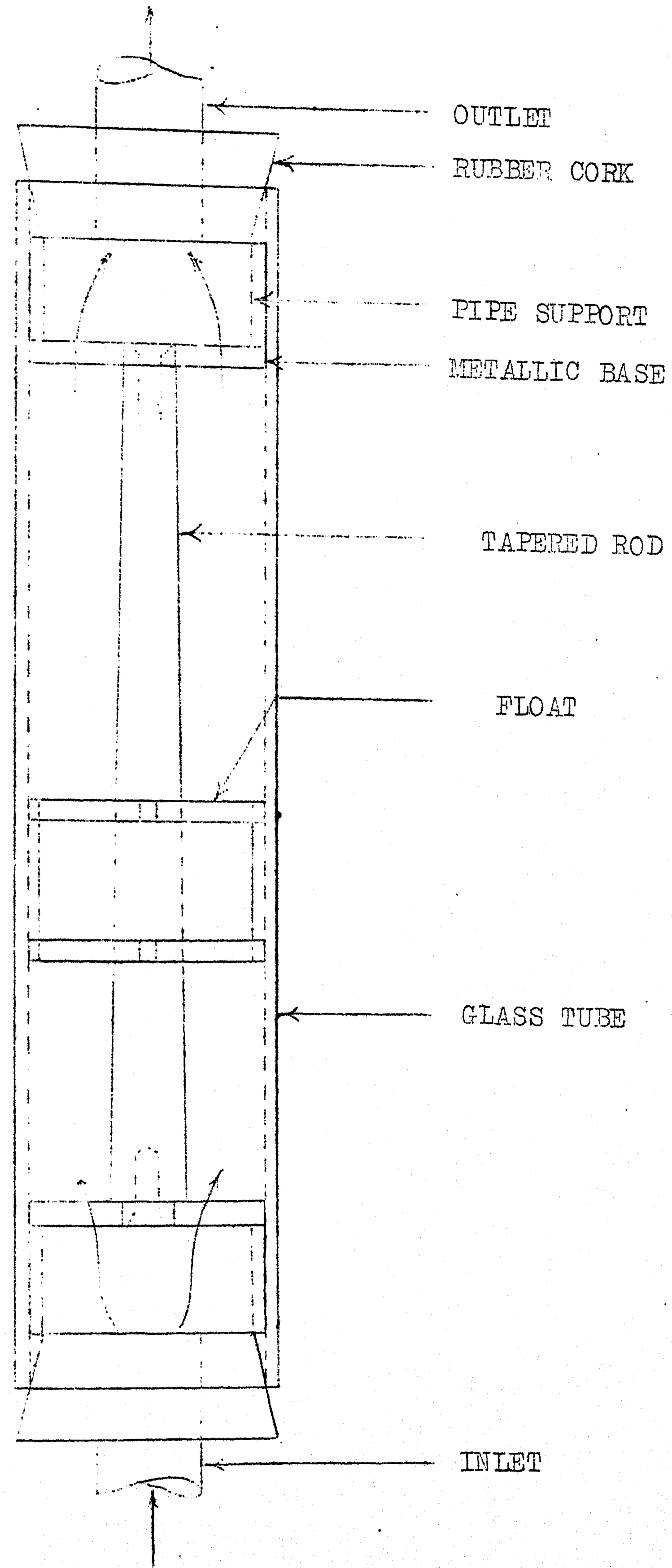


FIGURE 2: THE FLOWMETER

TABLE I: DETAILS OF TAPERED RODS

Rod No.	Approx. θ	C1 inch.	A1 inch.	H2 Cm.
1	1°	0.456	0.250	15.0
2	0.75°	0.402	0.250	15.0
3	0.50°	0.349	0.250	15.0
4	1.00°	0.590	0.380	15.05
5	0.75°	0.510	0.351	15.0
6	1.00°	0.590	0.250	24.65
7	0.75°	0.515	0.230	24.65

Float: The float, though small in size, is an important component of this flowmeter. Properties like stability of the float, which have a direct impact on the accuracy of the flowmeter were considered for design purposes. Unaided floats try to rotate as well as tend, not to remain concentric. Hence, to provide mechanical aid for stability, the outer diameter of the float was made of a size just sufficient to slide inside the glass tube. To reduce the friction between the glass tube and the float, the area of contact between the two was restricted to both ends of the float as shown in Figure 3b. Small vertical slots were made on this area to allow air, entrapped between the float and glass tube, to escape when the flowmeter is empty.

In accordance to Heads[10] work, a sharp-edged orifice was used to provide the necessary constriction to fluid flow in the glass tube. Following the conclusions of Stout and Rowe[2], this

orifice was designed at the bottom of the float in order to keep the centre of gravity as low as possible.

The dimensions of various portions of the float were selected using the following guide lines, based on the work of Head[10] for rotameter-type floats.

$$D2 \leq 0.8D1$$

$$0.5D1 \leqslant H1 \leqslant D1$$

$$H3 = 0.01\ D1 \pm 10\%$$

where $D2$ = orifice diameter

$D1$ = inner diameter of float

$H1$ = height of float

$H3$ = orifice thickness

The floats were made from aluminium, nylon, and teflon whose dimensions are given in Appendix 1.

Metallic Base Plate: Two circular metallic base plates made of brass, were screwed on to the tapered rod, one at each end, to keep it concentric with the glass tube. The thickness of this plate was 0.25 inches. To minimize pressure losses of the flowing liquid, the base was made of the shape as shown in Figure 3c.

Pipe Support: To support the tapered rod without choking the flow, a piece of thin metallic pipe having a diameter just sufficient to slide into the glass tube was employed at both the ends.

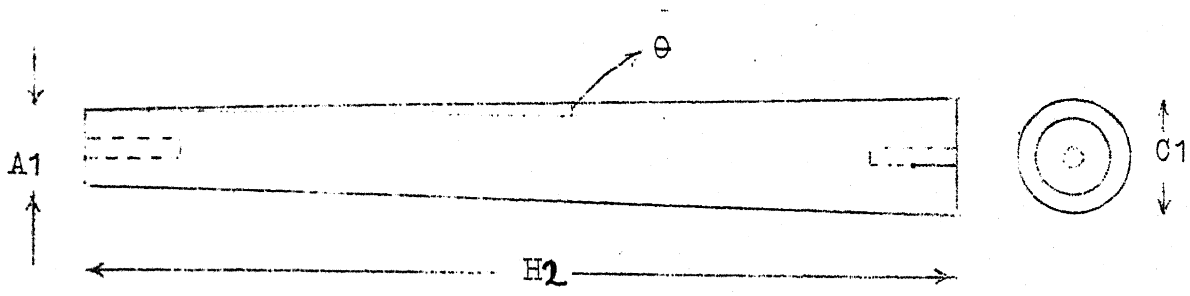


FIGURE 3a: TAPERED ROD

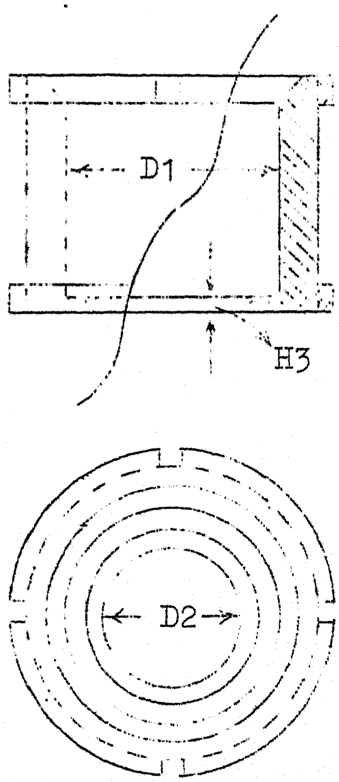


FIGURE 3b: THE FLOAT

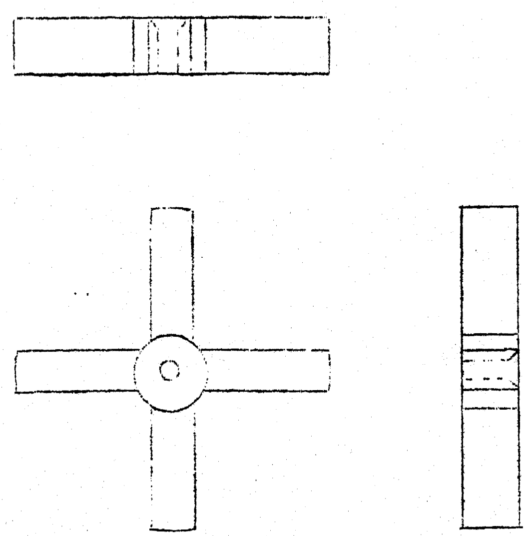


FIGURE 3c: THE METALLIC BASE

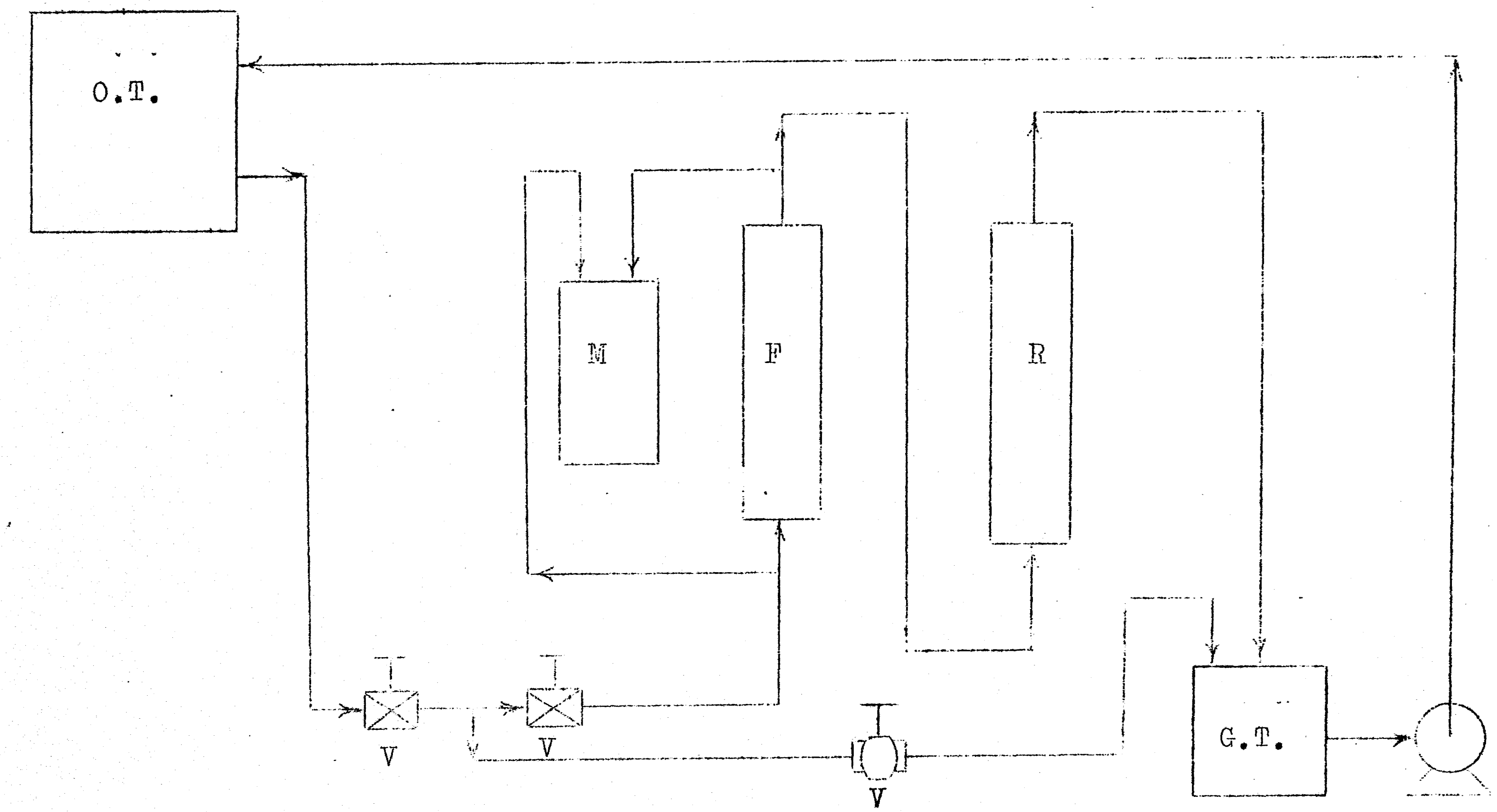
This pipe also helped in reducing the expansion effects, to be discussed later in detail. The different lengths of these pipe supports that were used are 1.1, 3.6, and 4.7 cm. respectively.

3.2 <u>Experimental Procedure</u>:

Water was used as fluid to check the performance of the flowmeter. It was made to flow from an overhead tank to the flowmeter. The upstream of the flowmeter consisted of a by-pass line. Two valves were employed to control and regulate the flow rate. Metal piping of 1/4" O.D. was used throughout, for making the connections. A schematic flow-diagram of the above system is shown in Figure 4.

To minimize fluctuations in flow, the use of reducers was avoided in the upstream section.[11] A manometer connected across the flowmeter, and a precalibrated standard rotameter in the downstream section served the purpose of indicating the total pressure drop and the flow-rate, respectively. The outgoing liquid was recycled to the overhead tank. With the available head a maximum flow rate of 3.5 l/min. was obtained. The range of flow covered was from 0.4 to 3.5 l/min. The overhead tank was of a very large capacity which ensured a constant head over any single observation. Throughout the experiments the temperature of water was 26 $\pm$ 2°C.

About 40 different sets of observations were taken using



F - Flowmeter under experimentation
R - Precalibrated Rotameter
M - CCl_4 Manometer
GT- Ground Tank
OT- Over head Tank

V - Valves
P - Pump

FIGURE 4: FLOW DIAGRAM OF THE EXPERIMENTAL SET-UP

rious combinations of different float sizes, taper rods etc.
each set, on the average, 13 readings were taken for
fferent flow rates. Repetition of flow measurements showed
od reproducibility.

CHAPTER IV

RESULTS

The changes in flowmeter properties such as; sensitivity, stability, rotation etc., which were observed during experimentatio[n] have been discussed under qualitative results. Results relating the effect of variables quantitatively, through mathematical models, have been grouped in quantitative results. Dimensional analysis and multiple linear regression analysis which were employed are given in Appendix 4 and 5 respectively.

5.1 Qualitative Results:

a) Calibration Curve: Linear relationships were obtained throughout the span between float height and liquid flow rate except, for a small initial portion ranging between 3 cm. to 4 cm. of float height. Log-log behavior was evident in this range. As an illustration the calibration curve for Rod No.1 and Float No.1 is shown in Figure 5.

b) Effect of Inlet and Outlet Pipe Diameters: The total pressure drop across the flowmeter was observed to increase for smaller inlet and outlet diameters. The calibration curve of the meter did not change in these cases. An illustration is shown in Figure 5. Pipes having 0.8 cm I.D. were used finally throughout the later experiments to match the other fittings of the set-up. The results are given in Table II.

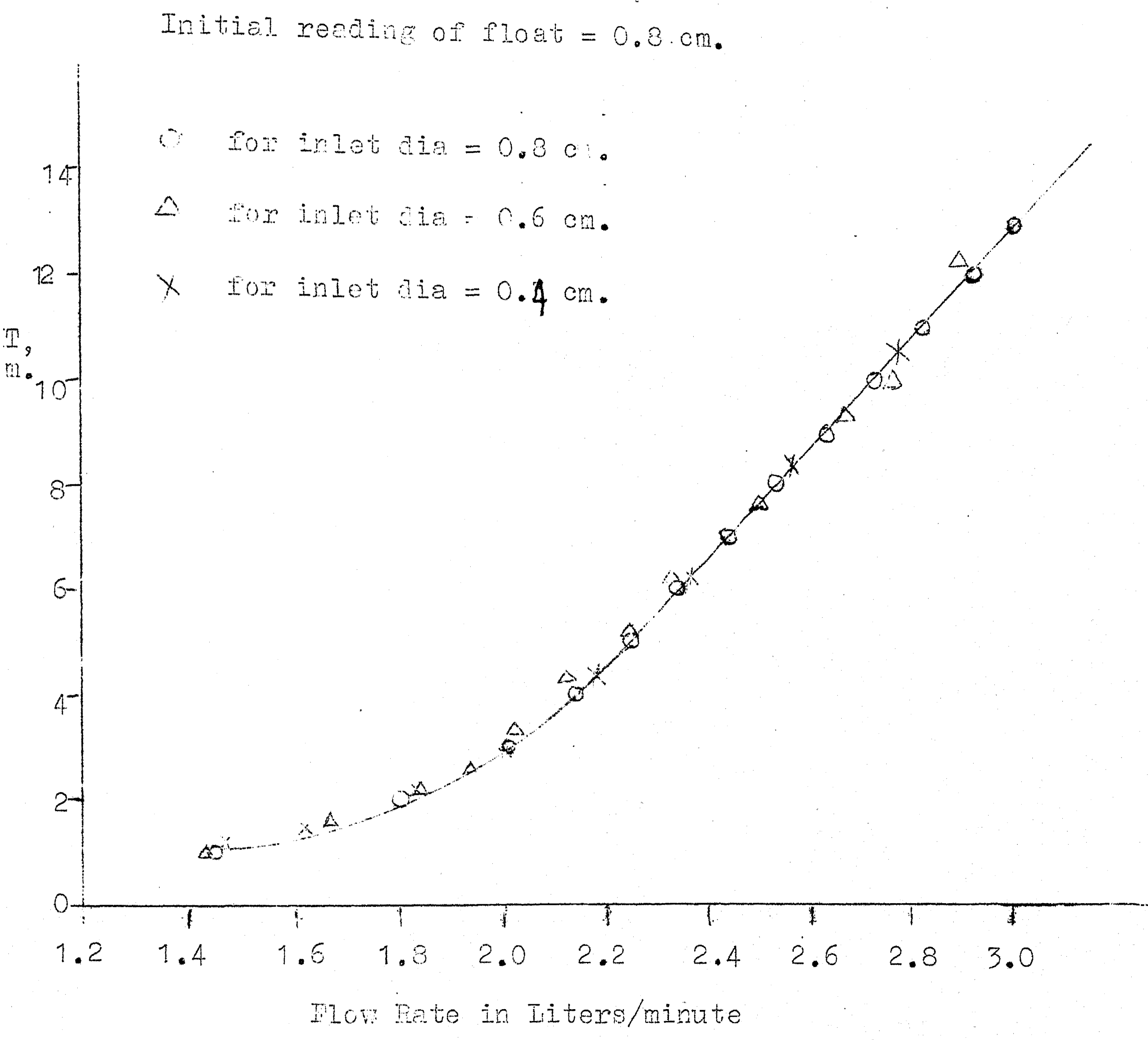


FIGURE 5: CALIBRATION FOR FLOAT 1 ROD 1

TABLE II: PRESSURE DROP FOR DIFFERENT INLETS AND OUTLETS

Flow-rate at which the data was taken - 3.04 litres/minute

Inlet and outlet pipe diameter in cm.	Difference in Height, cm. mercury
0.4	9.3
0.6	1.4
0.8	1.15

c) Effect of Inner Assembly on the Pressure Drop Across the Flowmeter: Experiments showed that the major contribution towards the total pressure drop across the flowmeter was only due to the inlet and outlet pipes. The inner assembly had a nominal effect on pressure drop.

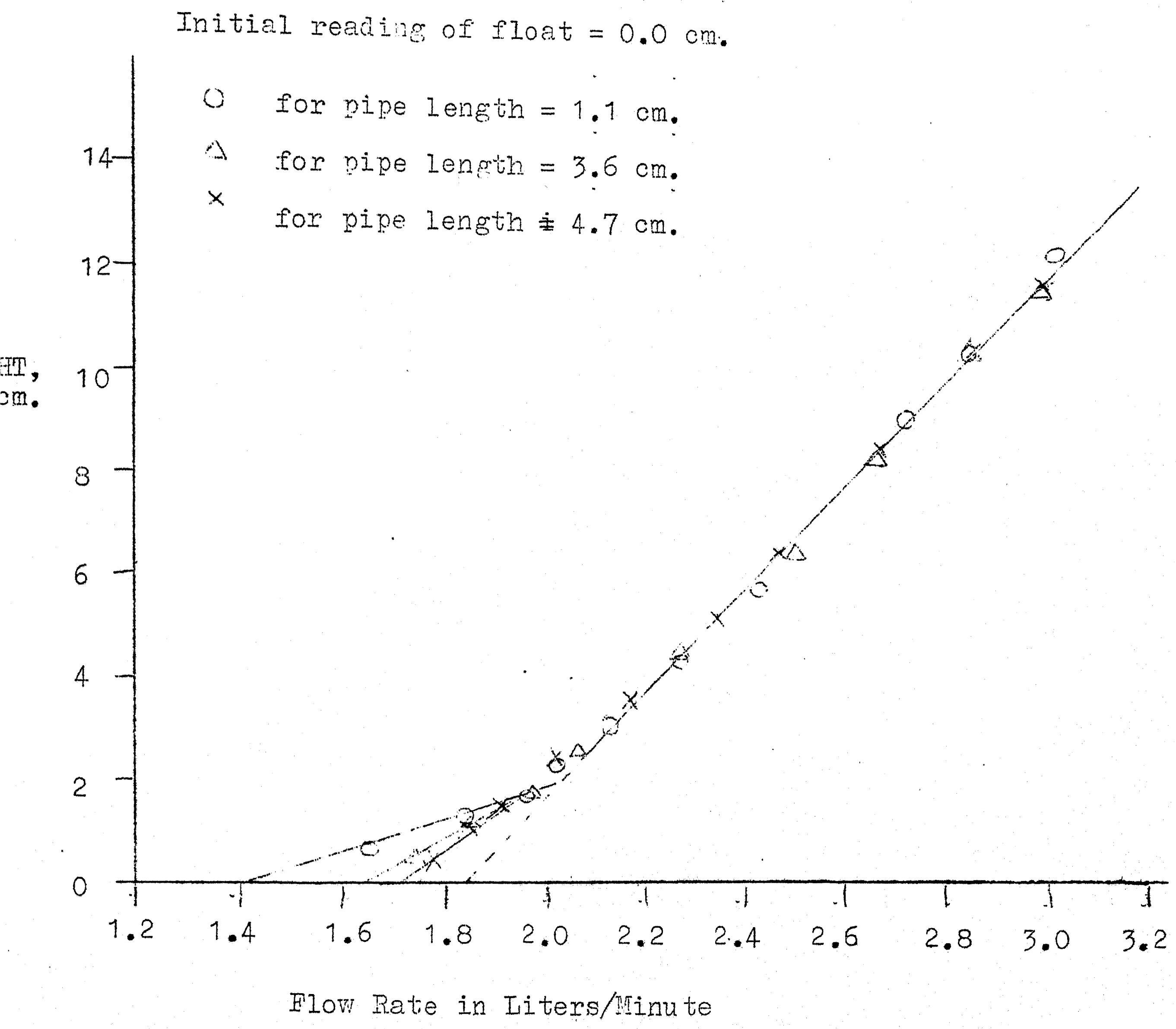
The results are shown in Table III below:

TABLE III: PRESSURE DROP DUE TO DIFFERENT COMPONENTS OF THE METER

Inlet and outlet pipe diameter	=	0.8 cm.
Observation flow rate	=	3.04 litres/minute
ΔH, for glass tube, only	=	1.15 cm. mercury
ΔH, for glass tube + metallic bases	=	1.15 cm. mercury
ΔH, for glass tube + metallic bases + tapered rod	=	1.25 cm. mercury

ΔH is difference in height of manometer reading.

d) Effect of Height of Metallic Pipe Support: The height of the metallic pipe support had an effect on the linearization of the lower portion of the calibration curve. An optimum height



— CALIBRATION FOR FLOAT 1 ROD 1

FIGURE 6: EFFECT OF PIPE LENGTH

of this support, with which an entirely linear calibration could be obtained, was found to exist. This height was different for different cases of the inner assembly and was found to depend on the taper angle (θ), the bottom diameter (C1) of the tapered rod and the slope of the upper portion of the calibration curve. A mathematical relationship of the above variables that was obtained is given in section 5.2 of this chapter. Figure 6 depicts the above effect as an illustration for the case of Rod No.1, Float No.1. The rest of the data are given in Appendix 2.

e) <u>Effect of the Bottom Diameter of the Tapered Rod</u>: For the same float and nearly the same taper angle of the rod, the slope of the calibration curve increased with an decrease in bottom diameter (C1) of the rod. As already discussed in the previous section, it governed the determination of the optimum height of the pipe support. The flowmeter showed better performance with larger bottom diameters.

f) <u>Effect of Orifice Annular Opening</u>: Observations showed that there was a particular limit to annular opening beyond which the flowmeter did not work satisfactorily. For (D2-D3) $\geqslant 0.3$, and Rod Nos. 2 and 3, light floats attained equilibrium after a very long time. A considerable amount of rotation was also observed in them. The above effect was seen to increase with a decrease in taper angle of the rod. Heavier floats did not however, show rotation and unstability to that extent.

g) Effect of Inner Diameter (D1) of the Float: Floats of nearly the same weight, but with smaller (D1), showed rotation a little before the limit of (D2-D3) $\geqslant$ 0.3 was attained. Floats having D1 = 0.78 inches worked quite well.

h) Effect of Taper Angle of Rods: The lesser the taper angle of the rod the more sensitive was the flowmeter. Figure 8 shows the calibration curves of the cases using Rods Nos 1,2, and 3, with float No.1. Observations with other rods and floats are given in the Appendix 3.

i) Top Taper on Float: There was no significant effect of the top taper of the float on the performance of the flowmeter. The taper was provided to avoid the sudden expansion of the fluid as it crossed the float.

j) Pressure Drop Across Floats: The pressure drop across floats, as seen in Figure 7 was nearly constant, except for the entrance region. The pressure drop due to Float No.1 was lesser than Float Nos. 2 and 10.

k) Effect of Float-Height: The heights tested in this study showed rotation-free performance in the limits of $\frac{D2-D3}{D} \leqslant 0.3$.

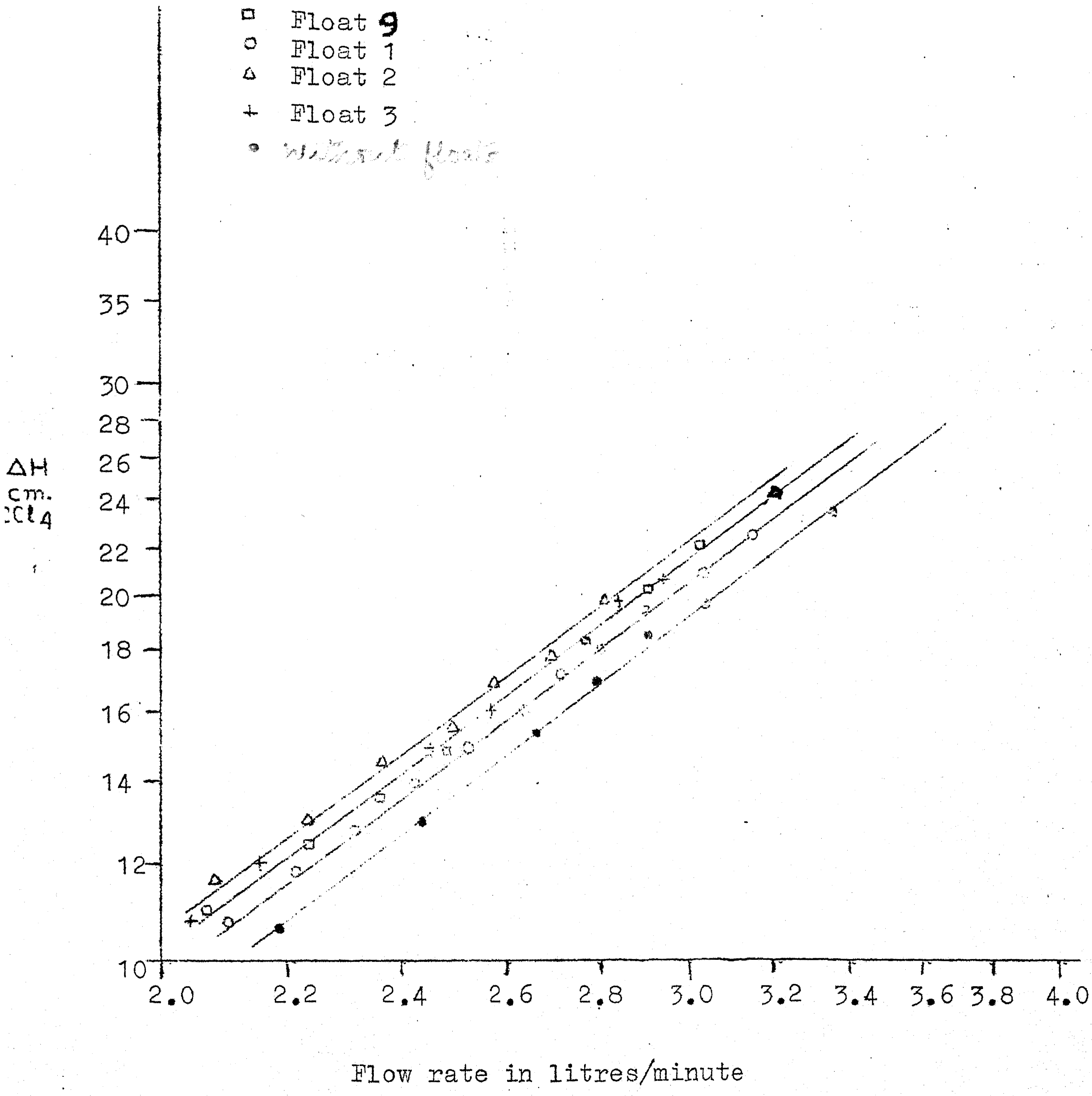
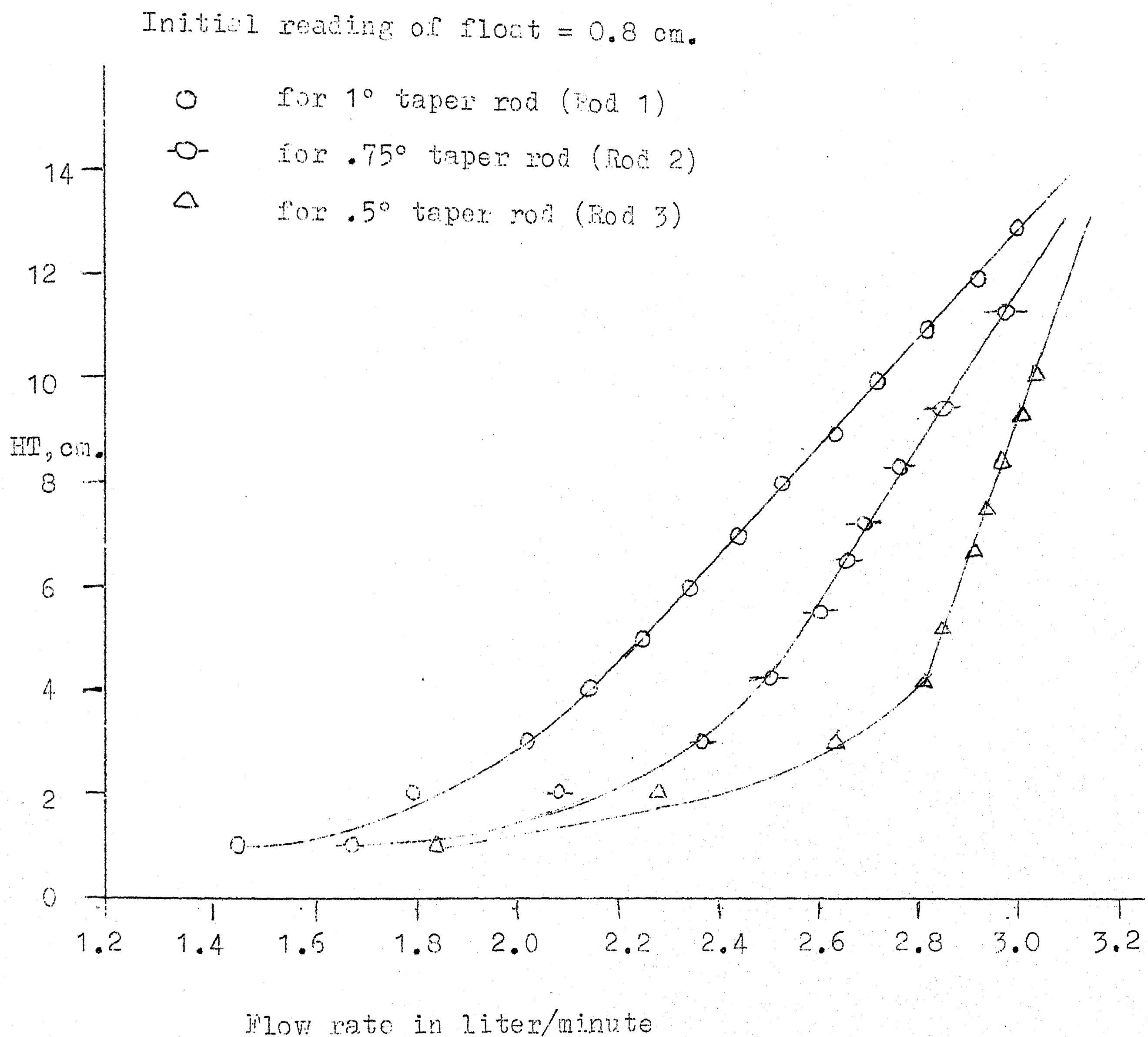


FIGURE 7: TOTAL PRESSURE DROP ACROSS THE FLOATS



CALIBRATION FOR FLOAT 1

FIGURE 8: EFFECT OF TAPER ANGLE OF ROD

4.2 Quantitative Results:

Multiple linear regression analysis was done to correlate the different dimensionless groups obtained through dimensional analysis. The form of the desired regression equation was

$$Y_i = B(0) + \sum_{I=1}^{p} B(I)\ X_i(I) + E_i \qquad (1)$$

where p = no. of independent variables

E_i = errors

B's = unknown regression coefficients

Three different cases were tried

i) Regression among the logarithms of the given variables

ii) Regression among the given variables

iii) Regression among the logarithm of the dependent variable and the given independent variables.

Results were also obtained by deleting the independent variables which had very small regression coefficients.

The best among all of the above was selected as the final regression equation. The selection was done on the basis of the following criteria[12]

i) The variance (RSS/DF) should be least. Here RSS is the residual sum of squares, and DF is the degree of freedom.

ii) The coefficient of correlation (R) should be the largest.

R^2 indicates the percentage of variation in Y that can be accounted for by linear regression on the given independent variables.

iii) The calculated value F', should be large

$$F' = \frac{\text{variance from linear regression}}{\text{variance of residuals from regression}}$$

When the value of F' is greater than the value obtained from the F-tables for the given degrees of freedom and 95% significance level, then the hypothesis that no regression among the given variables exists **is** rejected.

iv) For B(I)'s to be significant, the calculated T factor for the respective B(I) should be greater than the value given in the T-tables at 95% significance level, for the particular degree of freedom.

v) The calculated Durbin-Watson-statistics (D) should lie between the value DU and (4-DU) obtained from the D-tables for the specific degree of freedom. Then only the residuals will be independent of each other.

The Durbin-Watson test can be carried out only for cases which at the maximum, have 5 independant variables, because DU values beyond that are not available even in the original paper.[19]

a) <u>Correlation Among the Different Dimensionless Groups Obtained Through Dimensional Analysis</u>: In this case

$$Y = (D2 - D3)/D$$

$$X1 = \frac{Q}{D}\sqrt{\frac{\rho_W \cdot \rho_S}{WS \cdot G\ (\rho_S - \rho_W)}} \qquad X2 = H3/D$$

$$X3 = H1/D \qquad X4 = D1/D$$

$X5 = TAN\theta$

$X6 = U\sqrt{\frac{\rho_s}{\rho_w\, WS\, G(\rho_s - \rho_w)}}$

$X7 = C1/D$

TABLE IV: DIFFERENT TEST-VALUES

Number of independent variables = 7

Total number of variables = 8

Number of observation = 279

Degree of Freedom = 271

	Log Fit	Ordinary Fit	Semi-Log Fit
F'	1962.97	1039.13	833.87
R	0.9902	0.9819	0.9776
Variance	0.0029	0.0002	0.0066
RSS	0.7818	0.0495	1.7934

F' is much greater than the value obtained from the F-Tables corresponding to a degree of freedom 271. Hence linear regression in all the cases exists.

R in all the cases is quite large, showing 96-98% linear variation among the given variables.

The variance in the case of ordinary fit is the least, hence it is the best among the different fits tested.

Table V gives the coefficients of linear regression for the ordinary fit.

TABLE V: COEFFICIENTS OF REGRESSION

Degree of freedom for T = 273

B(0) =-0.0983

I	B(I)	Standard error in B(I)	T-Factor
1	1.0250	0.0176	58.1077
2	0.2999	0.0721	4.1599
3	0.0024	0.0210	0.1161
4	0.0818	0.0769	1.0628
5	-0.4383	0.3879	-1.1299
6	0.5715	0.1693	3.3768
7	-0.0411	0.0197	-2.0885

From the students 't' test, for a level of significance

	0.2	0.1
Significant variables	X1, X2, X5, X6, X7	X1, X2, X6, X7
Insignificant variables	X3, X4	X3, X4, X5

Deleting the variables X3 and X4, and performing the regression analysis it was found that the value of R decreased which implied that the new regression was no better than the previous one.

The final correlation among the variables is

$$\boxed{\begin{aligned} Y = {} & -0.0983 + 1.0250\,X1 + 0.2999\,X2 + 0.0024X3 + 0.0818X4 \\ & -0.4383X5 + 0.5715X6 - 0.0411\,X7 \end{aligned}} \qquad (2)$$

b) <u>Correlation for Pipe-Support Length:</u> In this case

$$Y = \frac{M'}{M}$$

where M' = slope of bottom calibration curve

M = slope of remaining curve

X1 = H4/D, X2 = TANθ, and X3 = C1/D.

Table VI depicts the different tests that were done.

TABLE VI: <u>DIFFERENT TEST-VALUES</u>

Number of independent variables = 3

Total number of variables = 4

Number of observations = 11

Degree of freedom = 7

	Log-Fit	Ordinary Fit	Semi-Log Fit
F'	42.0833	9.2501	55.9146
R	0.9734	0.8936	0.9798
Variance	0.0322	2.6089	0.0245
RSS	0.2252	18.2620	0.1717
D	1.9089	2.0686	1.5956

The value of DU obtained from D-Tables[13] for a sample size of 11, independent variables 3, and an upper tail of 0.01, is 1.46. It is evident that in all the above cases the value of D lies between DU and (4-DU) showing the residuals are independent of each other. Furthermore, the semi-log fit has the minimum variance alongwith a maximum value of R and F', hence

it is the best fit among the fits that were tried.

The coefficients of linear regression for this fit are given in Table VII.

TABLE VII. COEFFICIENTS OF REGRESSION

Degree of freedom for T = 11

B(0) = 5.4174

I	B(I)	Standard error in B(I)	T-Factor
1	-0.6239	0.0868	-7.1459
2	-36.2462	24.2510	-1.4946
3	-7.2029	1.3088	-5.5036

From the students 't' test, for a level of significance

	0.2	0.1
Significant variables	X1, X2, X3	X1, X3
Insignificant variables	-	X2

To get a completely linear calibration Y should have a value 1, then the final form of the correlation equation will be

$$\ln(1) = B0 + B1\ X1 + B2\ X2 + B3\ X3 \qquad (3)$$

or

$$\boxed{0.6239\ (H4/D) = 5.4174 - 7.2029\ (C1/D) - 36.2462\ (TAN\theta)} \qquad (4)$$

CHAPTER V

DISCUSSION

Linear calibration could not be attained in the lower end of the present flowmeter. This nonlinearity, was present in the initial 2 to 3 cms. of height.

In the case of sudden contraction, Kaye and Rosen[14] and Han[15] showed, for polymer solutions and newtonian fluids respectively that, the pressure drop per unit length in the entrance region was comparatively larger than in the remaining portion. This pressure-drop had a linear relationship with tube length in both the regions.

The present flowmeter, which is having a sudden expansion at the inlet definitely has an entrance region where disturbed flow exists. The case here is contrary to that dealt by Kaye and Rosen[14] and Han[15]. Therefore, the pressure drop per unit length in the entrance region should be comparatively smaller than that in the remaining portion of the meter. The length, as well as the pressure drop profile, in this region will depend on the resultant disturbances caused by the sudden expansion and the presence of the tapered rod.

The height of the float depends on the impact head[16], which in turn depends on flow-rate. For a stationary float at equilibrium

$$(p_2-p_1)\ Ao = V_s\ g(\rho_s - \rho) \qquad (5)$$

where p_2 = pressure at bottom of float

p_1 = pressure at the top of the float

Ao = average area of cross-section of the float

(p_2-p_1) includes two effects viz. the nearly constant pressure drop $\Delta p'$, caused by the float and the pressure drop, Δp, caused by the liquid flowing through the tapered annulus.

The value of (p_2-p_1), and the calibration curve will depend mainly on the nature of variation in Δp, because $\Delta p'$ in its comparison, is quite small and constant. A greater impact head and hence a greater flow rate will be required to lift the float to a particular height when Δp is smaller, because in that case p_1, which is the pressure on float top, will be greater.

The log-log behavior shown in an increasing order, by the calibration curve in the initial range (Fig. 5), is therefore, due to the entrance region which has a log-log pressure-drop-variation in the decreasing order. Hence, to get a constantly linear calibration, it is necessary to avoid the entrance region, by varying the length of the metallic support.

The effect of sudden expansion gets neutralized to some extent by the subsequent sudden contraction offered by the bottom of the tapered rod. Complete neutralization of the above effect can be achieved by adjusting appropriately the dimensions of the bottom diameter of the rod, and the pipe support. Smaller bottom diameters will provide lesser constriction and hence a lesser pressure drop. To have the same neutralizing effect, smaller bottom diameters will therefore

need longer pipe supports as compared to bigger ones, so that the pressure gets reduced to an amount that can be neutralized by the available constriction. It was seen that rods having bottom diameters more than 0.5 inches required very small pipe supports.

The calibration line for a flowmeter having smaller taper-angled rod has greater slope than that having larger taper-angled rod of the same bottom diameter. Hence, to bring the lower end of the calibration curve in line with the upper portion, it is necessary to provide an extra pressure-drop than that required for larger taper angled rods. A longer pipe support will do the needful.

For sharp-edged annular orifices, Bell and Bergelin(17) showed that the discharge coefficient (C), for a fixed Reynolds number decreases with an increase in the value of Z. Z is the ratio of orifice height, L, to annular opening, $\frac{D-d}{2}$. To get higher discharge coefficients it is necessary to have a low value of Z, which can be done in the present case by either reducing $\frac{H3}{D}$ or increasing $\frac{D2-C1}{D}$. The restriction $\frac{D2-A1}{D} \leqslant 0.3$ limits the choice of $\frac{D2-C1}{D}$. In a typical example where $\frac{D2-A1}{D} = .3$, $\frac{D2-C1}{D} = .01$, $\frac{D2}{D} = .6$ and taper angle = 1°, the height of the rod comes out to be about 15 cm. Therefore, if $\frac{D2-C1}{D}$ is taken much greater than .01, the range of the meter will decrease appreciably. Bell and Berglins(17) work showed that nearly for all Reynolds Numbers the orifice coefficient

was minimum and remained constant for $Z=0.1$ to 0.4. Hence in the present case it will be desired to have $\frac{H3}{D} \gtrsim .01$ and $\frac{D2-C1}{D} \gtrsim .02$.

Effective length as well as sensitivity of the meter depends on the ~~tapper~~-angle of the rod. Both of these will be small for bigger ~~tapper~~-angles. As explained by Kaufman[18] the taper-angle cannot be taken more than 8°, beyond which separation of flow occurs. In the given constraints the effective length of the rod for 1° taper will approximately be 15 cm. The sensitivity change in 1° taper and 0.5° taper is also considerable. For taper angles more than 2° the effective length as well as the sensitivity will be quite low.

By increasing the float height it is expected that rotation will start earlier than the limit of $\frac{D2-D3}{D} \geqslant 0.3$. However, greater float heights were not tested.

It is believed that the length of the vena-contracta, which depends on the annular orifice opening, is very small when $\frac{D2-D3}{D} \geqslant 0.3$. Hence, the flowing fluid starts expanding in the float quite near its bottom. The smaller internal diameter or the greater float height disturbs the stream-lines near the surface, allowing them not to expand in their usual way. Because of this, it appears, some angular forces may come into action imparting rotation to the float. The exact reason of rotation is not clear.

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions: A flowmeter was constructed with a constant sided glass tube having a concentric tapered rod alongwith an annular float. The float slided along the inner wall of the glass tube.

Senstivity of the meter increased with a decrease in the taper angle of the rod. High senstivity can thus be achieved simply, by using a rod having a very small taper. In the conventional rotameter, this could have been achieved, only by resorting to the complicated design of Tarish.(9)

A linear calibration was found to exist between the float height and the flow rate.

Heavier floats were more stable.

The flowmeter showed a minimum of 99.5% reproducibility.

Rotation in floats was evident after (D2-D3)/D increased beyond 0.3.

With regard to the design of the flowmeter, it is concluded that the following constraints should be observed.

i) $(D2-A1)/D \leq 0.30$

ii) $(D2-C1)/D \geq 0.02$

iii) $C1/D \geq 0.50$

iv) $D1/D \geq 0.78$

v) $H3/D \leq 0.01$

vi) $H1/D \leqslant 0.595$

vii) $\theta \leqslant 2^\circ$

By selecting the dimensions of the float within the limits of the above constraints, the weight of the float can be calculated. The flowmeter can then be designed for the given specifications by using the mathematical relationships obtained in Chapter IV.

The fabrication cost of the flowmeter in the laboratory is estimated to be Rs.25.0. This does not include the cost of the outer case and the permanent scale that will have to be used however, when this flowmeter is exploited commercially. The details of the cost estimation are given in Appendix 6.

If this flowmeter is produced in bulk, the estimated cost of production of a 1-inch and a 2-inch diameter flowmeter will in any case not exceed Rs.75 and Rs.100 respectively. The present market rates of 1 inch and 2-inch rotameters are Rs.1200 and Rs.2000 respectively.

The flowmeter is also capable of measuring opaque and translucent liquids. It is very cheap as compared to the present rotameters.

6.2 Recommendations:

a) In Reference to Flowmeter Design: It is recommended that the float, whenever possible, be made from materials having high density to ensure stability and rotation-free flow. Stainless

steel may be used as the material of construction.

For very low flow-rates, glass tubes having appreciably small diameters, will be required, making it difficult to construct the flowmeter. This can be eluded by constructing floats out of thermosetting plastics, like; urea formaldehyde and cotton flock phenolics whose specific gravity lies in the range of 1.3 to 1.5.

The material of construction of the inner assembly has to be appropriately selected, from an economic standpoint, depending on the fluid to be metered. Except in the cases of concentrated acids and alkalis, thermosetting plastics may be used for the construction of the inner assembly, other than the float.

Using moulding processes to prepare floats and tapered rods, the necessity of calibrating individually each flowmeter of the same size and capacity can be eliminated.

b) Recommendations for Future Study: The study of rotation in floats which is a general problem in all float-type flowmeters may be carried out.

Experiments on the flowmeter using different liquids and glass tube diameters, may be made to check the validity of the mathematical relationships obtained among the different dimensionless groups in the present work.

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LITERATURE CITED

1. Stepenas Kolupaila, "Bibilography of Hydrometry", Univ. of Notre Dame Press, Indiana 1961, p.317.

2. Stout L.E. and Rowe, A.R., "A new type of fluid rate flowmeter" Trans. A.I.Ch.E. 34, 1, 1938.

3. Fisher, Belchman, S. and Lipstien, E., 'Elimination of viscosity as a factor determining rotameter calibration', Trans. A.I.Ch.E., 36, 857, 1940.

4. Kintner, R.C. 'Visual fluid flowmeters with straight walled tubes', Ind. Eng. Chem. Anal. Ed.14, 261, 1942.

5. Coleman, M.C., 'Variable area flowmeters', Trans. Inst. Chem. Engrs., 34, 4, 339, 1956.

6. Danckwerts, P.V., and Sikder, A.K.'Perforated tube flowmeter', C.E.S. 13, 34, 1961.

7. Kehat,E., 'Constant cross-section variable area flowmeter', C.E.S. 20, 425, 1965.

8. Ibrahim, S.H. and Kuloor, N.R., 'A constant cross-section variable area flowmeter', C.E.S. 22, 243,1967.

9. Tarish, M.S. 'Highly sensitive rotameter', Measurement techniques no.4, 353, Sept. 1965.

10. Head, V.P. 'Coefficients of float type variable area flowmeters' Trans A.S.M.E. 76, 851, 1954.

11. Shafer and Ruegg , 'Liquid, flowmeter calibration techniques', Trans A.S.M.E. 1369, 1958.

12. Braynant, E.C. 'Statistical analysis', second edition, McGraw-Hill, p.212.

13. Himmelblau, D.M., 'Process analysis by statistical methods', John Wiley and Sons, p.113.

14. Kaye, S.E. and Rosen, S.L. 'Dependence of laminar entrance loss coefficient on contraction ratio for newtonian fluid', A.I.Ch.E.J. 1269, Sept. 1971.

15. Chang Dae Han, 'Entrance region flow of polymer melts', A.I.Ch.E. 1480, Nov. 1971.

16. Schoenborn, . ., and Colburn, . ., 'Performance of Rotameter', Trans. A.I.Ch.E., 359, 1939.

17. Bell, K.J. and Bergelin, O.P., 'Flow through annular orifices', Trans A.S.M.E., Vol.1, 593, 1957.

18. Kaufmann, W., 'Fluid Mechanics', McGraw Hill Book Co., Inc. p.112.

19. Durbin, J. and Watson, G.S., Biometrica 38, 159, 1951.

APPENDIX 1

TABLE 1-A: DETAILS OF FLOATS

Float No.	Mat. of Construction	Wt.(WS) (g)	ρ_s (g/cc)	D1 inch.	D2 inch.	H1 inch.	H3 inch.
1	Al	5.7975	2.715	0.78	0.605	0.495	0.040
2	Al	6.9695	2.715	0.78	0.600	0.595	0.054
3	Al	6.0315	2.715	0.78	0.604	0.505	0.075
4	Nylon	3.0160	1.430	0.78	0.605	0.490	0.064
5	Teflon	4.5680	2.152	0.72	0.605	0.495	0.069
6	Al	7.1855	2.715	0.78	0.605	0.496	0.054
7	Al	7.0010	2.715	0.78	0.601	0.595	0.065
8	Al	5.7150	2.715	0.78	0.631	0.495	0.061
9	Al	5.6335	2.715	0.77	0.606	0.480	0.075
10	Al	5.6235	2.715	0.78	0.675	0.495	0.062
11	Al	5.6940	2.715	0.78	0.602	0.495	0.059
12	Al	6.6805	2.715	0.72	0.605	0.495	0.054

Float Nos. 11 and 12 had top taper angle of 30°, while in the rest of the floats it was 15°.

APPENDIX 2

Values of the slope of the upper and lower portions of the calibration curves for Float No.1, using different tapered rods and different heights of pipe supports are given in Table 2.A

TABLE 2.A. SLOPES OBTAINED FOR DIFFERENT PIPE SUPPORTS

Rod No.	Values of M1 for Different H4			M
	H4=1.1	H4=3.6	H4=4.7	
1	0.3250	0.2060	0.1440	0.1000
2	0.3300	0.1900	0.1700	0.0700
3	0.4810	0.2480	0.1445	0.0407
4	0.1700	0.1489	-	0.1489
7	0.1930	0.0715	-	0.0715

H4 = height of pipe support in cm.

M1 = slope of the lower curve

M = slope of the upper curve

APPENDIX 3

METER CALIBRATION FOR THE CASES OF DIFFERENT FLOATS AND RODS

Initial reading of float for all cases = 0.8 cm.

Height of pipe support for all cases = 1.1 cm.

HT = Height of Float in cm.

Q = Volumetric flow rate in Litre/min.

TABLE 3-A: CALIBRATION FOR ROD 1

HT	Float 1	Float 2	Float 3	Float 4	Float 5	Float 6	Float 7	Float 8
	Q	Q	Q	Q	Q	Q	Q	Q
1.0	1.4458	1.5333	1.3932	0.5934	1.0838	1.7085	1.5333	1.6443
2.0	1.7961	1.8720	1.6968	0.8678	1.3348	1.1172	1.8603	2.1581
3.0	2.0238	2.1172	1.9304	0.9262	1.5330	1.3741	1.1055	2.4675
4.0	2.1405	2.2573	2.0471	0.9612	1.6092	2.5025	2.2456	2.6426
5.0	2.2456	2.3741	2.1581	1.0079	1.7027	2.6193	2.3799	2.8295
6.0	2.3390	2.4792	2.2573	1.0488	1.7727	2.7069	2.4792	2.8645
7.0	2.4441	2.5901	2.3566	1.1247	1.8720	2.8061	2.5959	2.9930
8.0	2.5259	2.7244	2.4558	1.1947	1.9420	2.8820	2.7302	3.0513
9.0	2.6368	2.8295	2.5726	1.2473	2.0238	2.9930	2.8178	3.2190
10.0	2.7244	2.9346	2.6660	1.2940	2.0997	3.0455	2.9171	
11.0	2.8178	3.0397	2.7477	3.3407	2.1756	3.1480	3.0280	
12.0	2.9229	3.1480	2.8412	—	2.2456	3.2440	3.1480	
13.0	3.0046	3.2440	2.9171	1.4341	2.3099		3.2190	
14.0	3.1480		3.0455	1.5042	2.4325			

TABLE 3-B: CALIBRATION FOR ROD 2

HT	Float 1 Q	HT	Foat 2 Q	HT	Float 3 Q	HT	Float 4 Q	HT	Float 5 Q
1.0	1.6793	1.0	1.8311	1.0	1.6268	1.5	0.9904	1.0	1.2940
2.0	2.0880	2.0	2.2048	2.0	2.0238	2.0	1.0896	2.0	1.6443
3.0	2.3741	3.0	2.5492	3.1	2.3215	4.8	1.2414	2.9	1.8311
4.2	2.5025	4.2	2.6777	4.1	2.4208	5.6	1.2765	4.6	1.9654
5.6	2.6018	5.2	2.7477	5.4	2.5142	6.7	1.3115	6.2	2.0296
6.7	2.6660	6.1	2.8120	6.1	2.5667	8.5	1.3699	7.1	2.0763
7.2	2.7010	7.2	2.8937	7.1	2.6426	9.9	1.4283	8.3	2.1347
8.4	2.7769	8.1	2.9754	8.6	2.7361	10.9	1.4808	9.8	2.2048
9.5	2.8645	8.7	3.0280	9.2	2.7711	12.0	1.5509	10.7	2.2573
11.5	2.9930	9.7	3.1000	11.2	2.8995	12.8	1.6034	11.7	2.3040
						13.9	1.6326	12.5	2.3507
								13.8	2.4208

TABLE 3-C: CALIBRATION FOR ROD 3

HT	Float 1 Q	HT	Float 2 Q	HT	Float 3 Q	HT	Float 4 Q	HT	Float 5 Q
1.0	1.8369	1.0	1.9829	1.0	1.7786	2.2	1.2531	1.2	1.4983
2.0	2.2865	2.0	2.4266	2.0	2.2398	5.9	1.3757	2.0	1.8253
3.0	2.6426	3.0	2.8295	3.2	2.5521	6.7	1.2816	3.3	2.1522
4.2	2.8120	4.2	2.9871	4.4	2.7244	8.5	1.4166	4.4	2.1989
5.1	2.8528	4.9	3.0397	6.3	2.8120	8.9	1.4341	5.4	2.2223
6.9	2.9229	5.6	3.0513	7.3	2.8528	9.3	1.4574	6.1	2.2456
7.6	2.9462	6.3	3.1000	8.3	2.8879	11.0	1.5333	8.2	2.3157
8.6	2.9696	7.8	3.1715	9.2	2.9171	12.2	1.5917	10.1	2.3624
9.3	3.0105	8.2	3.1960	9.9	2.9521			11.1	2.4033
0.1	3.0280	8.8	3.2441	10.8	3.0046			12.6	2.4733
2.1	3.1480			11.4	3.0105			13.8	2.5200

TABLE 3-D: CALIBRATION FOR ROD 4

	Float 1		Float 2		Float 4		Float 5		Float 3
HT	Q	HT	Q	HT	Q	HT	Q	HT	Q
1.0	0.2640	1.0	0.2090	1.0	0.1700	1.0	0.1850	1.0	0.2325
2.0	0.4241	2.0	0.3949	2.2	0.2170	2.0	0.3073	2.0	0.3890
3.0	0.5759	3.0	0.5992	3.3	0.3014	3.0	0.4241	3.0	0.5525
4.0	0.7744	4.0	0.7744	4.4	0.3540	4.0	0.5408	4.0	0.7043
5.0	0.9378	5.0	0.9845	5.4	0.4124	5.1	0.6693	5.0	0.8794
6.0	1.1071	6.1	1.7772	6.9	0.5175	6.0	0.7919	7.0	1.2064
7.1	1.2706	8.0	1.4866	8.7	0.6517	7.0	0.9145	8.2	1.3757
8.1	1.4049	9.3	1.6910	10.7	0.8094	9.1	1.1655	10.1	1.6443
9.2	1.5625	10.6	1.8895	12.6	0.9437	10.1	1.2881	11.1	1.7727
10.5	1.7552	11.2	1.9771	13.8	1.0196	11.1	1.4049	12.0	1.9012
12.0	1.9712	12.0	2.1172	12.4	0.9320	12.1	1.4107	12.7	2.0004
13.0	2.0822	13.1	2.2340			12.6	1.5684	13.2	2.0471
14.4	2.2748	14.0	2.2982			13.4	1.6443	14.0	2.1581

TABLE 3-E: CALIBRATION FOR ROD 5

HT	Float 1 Q	HT	Float 2 Q	HT	Float 3 Q	HT	Float 4 Q	HT	Float 5 Q
1.0	1.1305	1.0	1.1655	1.0	1.0429	2.1	0.6226	1.0	0.6342
2.0	1.2531	2.0	1.3582	2.0	1.2531	3.8	0.6693	2.1	1.0254
3.0	1.4633	3.0	1.5100	3.0	1.3699	4.5	0.7044	3.3	1.1247
4.0	1.5567	3.9	1.6268	4.0	1.4750	5.5	0.7685	4.3	1.2064
5.0	1.6501	4.9	1.7260	5.1	1.5720	6.2	0.8094	5.8	1.2531
6.0	1.7494	6.5	1.9070	6.5	1.7319	7.6	0.8678	7.2	1.4283
7.0	1.8545	8.2	2.0997	8.0	1.8778	9.5	0.9845	8.7	1.5567
9.0	2.0588	9.5	2.2456	9.6	2.0355	10.8	1.0429	9.9	1.6618
10.1	2.1639	11.0	2.3858	11.0	2.1756	12.2	1.1247	11.7	1.8253
11.0	2.2456	12.4	2.5084	12.1	2.3974	13.8	1.2064	12.4	1.8837
12.0	2.3390	13.0	2.5551	13.1	2.3624	13.5	1.1889	13.8	2.0063
13.0	2.4208	13.8	2.6543	14.0	2.4500				

TABLE 3-F: CALIBRATION FOR RODS 6 & 7

ROD 6				ROD 7			
Float 1		Float 2		Float 1		Float 2	
HT	Q	HT	Q	HT	Q	HT	Q
1.0	0.3715	1.0	0.3598	1.0	1.1363	1.0	1.2181
2.0	0.5000	2.0	0.5058	2.0	1.3348	2.0	1.3582
3.0	0.6926	3.0	0.6926	3.0	1.4574	3.0	1.5158
4.0	0.8794	4.0	0.8678	4.0	1.5275	4.0	1.6151
5.0	1.0429	5.0	1.0488	5.0	1.6151	5.0	1.7202
6.0	1.1714	7.2	1.3874	7.6	1.8720	6.0	1.8369
7.0	1.3057	8.7	1.6151	9.1	2.0238	8.8	2.1114
8.0	1.4574	11.4	2.0063	11.7	2.2398	10.7	2.2923
10.1	1.7377	13.6	2.3219	14.0	2.4325	12.8	2.4792
13.2	2.1114	15.8	2.5492	16.5	2.6368	14.0	2.5901
15.5	2.3741	17.2	2.7302	18.3	2.8003	16.0	2.7653
17.1	2.5492	18.5	2.8762	20.8	2.9930	18.2	2.9462
19.6	2.8120	20.2	3.0760	22.0	3.1000	20.0	3.1240
20.8	2.9229	21.5	3.1960	23.5	3.2190	21.3	3.2440
22.6	3.1240	19.3	2.9462				

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APPENDIX 4

DIMENSIONAL ANALYSIS

As a first step to **do** dimensional analysis of the variables of the flowmeter it was necessary to identify those variables that affect the drag force R, acting between the flowing fluid and the stationary float. It has been seen that R is affected by the velocity **V**, density ρ & the viscosity U of the fluid, and various geometric dimensions pertaining to the configuration of the tube and float, and to the orientation and position of the float.

Among these dimensions a characteristic length, D, designating the diameter of the meter tube was **selected.** Using this characteristic length all other lengths were expressed as dimenionless ratios, X1, X2, X3, --------Xn.

From a practical stand point, it is easier to use the flow**rate** Q through the tube rather than the fluid velocity. Hence the former was used in the present analysis. The dimensionless length ratios are;

$$X1 = \frac{D2-D3}{D}, \quad X2 = \frac{D1}{D}, \quad X3 = \frac{H1}{D}, \quad X4 = \frac{H3}{D}, \quad X5 = \frac{C1-A1}{2H2}, \quad X6 = \frac{C1}{D}$$

where D2-D3/D is a function of float height.

Subject to the limitation of incompressible fluid, the interdependence of all the variables can be expressed in the following form:

$$F(R, Q, \rho, U, D, X1, X2, X3, X4, X5, X6) = 0 \qquad (4.1)$$

Equation 4.1 consists of 5 dimensional quantities and 6 dimensionless length ratios, expressible in terms of three basic dimensions, viz. mass length and time. In accordance with Buckingham's[18] Pi theorem, equation 4.1 was expressed in terms of (5+6)-3 = 8 independent dimensionless groups. Equation 4.1 can hence be written as

$$f(\Pi 1, \Pi 2, X1, X2, X3, X4, X5, X6) = 0 \qquad (4.2)$$

where 1 and 2 are two dimensionless groups consisting of R, Q, ρ, U and D. By arranging the above quantities in the form of quotient such that the physical dimensions cancel the following was obtained.

$$\Pi 1 = \frac{Q}{D}\sqrt{\frac{\rho}{R}}$$

$$\Pi 2 = U/\sqrt{\rho R}$$

subsequent substitution of these values in equation 4.2 gave

$$f\left(\frac{Q}{D}\sqrt{\frac{\rho}{R}}, \frac{U}{\sqrt{\rho R}}, X1, X2, X3, X4, X5, X6\right) = 0 \qquad (4.3)$$

If the consideration however, be restricted to a single float, at one given float position in a particular metering tube equation 4.3 will simplify to

$$\frac{Q}{D}\sqrt{\frac{\rho}{R}} = \phi\left(\frac{U}{\sqrt{R\rho}}\right) \qquad (4.4)$$

As stationary float is unrestrained in the vertical direction, the drag force must exactly balance the force of gravity.

Hence $R = g\, V_f\, (\rho_f - \rho)$ (4.5)

where g = acceleration due to gravity

V_f = volume of float

$_f$ = density of float

= density of fluid

Or, $R = g\, m_f\, (\rho_f - \rho)/\rho_f$ (4.6)

here m_f = mass of float.

Now, the unknown variable R of equation (4.3) can be eliminated with the help of equation (4.6) to give a relationship among the known variables, only.

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APPENDIX 5

MULTIPLE LINEAR REGRESSION

Basic Assumptions Underlying the Estimation Procedure:

1. The expected value of $\bar{Y}_i$, given X_i, is a linear (in the parameters) function.

2. The values of X selected for experimentation are not random variables.

3. The variance of residuals, equals the variance of $\bar{Y}_i$, and may be constant or vary with X.

4. The observations of Y are mutually independent, i.e. the errors are statistically independent.

Based on these assumptions only the method of least squares yields unbiased estimators of regression coefficients B's, these will then have the smallest variances among the group of all unbiased linear estimators. It is therefore, necessary to check the extent to which the above assumptions are valid. Here $\bar{Y}_i$ is the dependent variable, while X's are independent variables.

Computational Procedure Adopted for Regression Analysis:

Step-1 Preliminary Computations

1. Selection and Transgeneration:

Subsamples are selected according to the specification on the selection card and data are transgenerated according to the codes.

2. Sums:

$$SX(J) = \sum_{I=1}^{N} X(I,J) \qquad J = 1, ----M1$$

where M1 = Total number of variables

N = Total number of observations

3. Means:

$$\bar{X}(J) = (\sum_{I=1}^{N} X(I,J))/N, \qquad J = 1, ----M1$$

4. Cross-Product Sums:

$$S(K,J) = \sum_{I=1}^{N} X(I,K)\ X(I,J), \qquad J,K = 1, ----M1$$

5. Cross-Product of Deviations:

$$G(K,J) = \sum_{I=1}^{N} (X(I,K)-\bar{X}(K)(X(I,J)-\bar{X}(J)$$

$$J,K = 1, -----M1$$

or $G(K,J) = S(K,J) - (SX(K)^{*}SX(J)/N$

6. Simple Correlation Coefficients:

$$SCORM(I,J) = \frac{G(I,J)}{\sqrt{G(I,I)G(J,J)}} \qquad I,J = 1, -----M1$$

<u>Step-2 Regression Computations</u>[12]

1. Inversion:

C(I,J) = p x p Matrix, and is the inverse matrix of G(I,J) $\qquad$ I,J = 1----p

2. Regression Coefficients:

$$B(I) = \sum_{J=1}^{p} C(I,J)\ G(J,M1), \qquad I = 1, ----p$$

If $YG(J) = G(J,M1)$ where $J = 1,----M1$

Then $B(I) = \sum_{J=1}^{p} G(I,J)\ YG(J)$

3. Intercept:

$$B(0) = \overline{X(M1)} - \sum_{I=1}^{p} (B(I)\ \overline{X(I)}$$

4. Sum of Squares Atributable to regression

$$D = \sum_{I=1}^{p} B(I)\ YG(I)$$

Tests to check that the assumptions for linear regression do not get voilated.

5. Sum of squares of deviation from regression:

$$RSS = YG(M1) - D$$

6. Coefficient of determination and multiple correlation Coefficient:

$$R^2 = D/YG(M1)$$

$$R = \sqrt{R^2}$$

7. Variance and standard error of estimate:

$$VEROR = RSS/(N-p-1)$$

$$S = \sqrt{VEROR}$$

here $(N-p-1)$ = Number of degrees of freedom = DF

8. Standard deviation of regression coefficients:

$$VCOVM(I) = \sqrt{VEROR \cdot C(I,I)} \qquad I = 1,\ldots\ldots p$$

9. T-values (to test the hypothesis that B(I)'s are zero):

$$T(I) = B(I)/VCOVM(I), \qquad I = 1,----p$$

10. F-Values (to test the hypothesis that there exists no regression):

$$F = (D/p)/(RSS/DF)$$

Step 3: Test of Autocorrelation of Residuals[13]

1. Error in calculated value of Y:

$$U(I) = Y-(B0 + B(1)\ X(1)+ \text{-----}\ B(p)X(p))$$

$$I = 1,\text{-----}N$$

2. Residual sum of squares

$$UISQS = \sum_{I=1}^{N} U(I)^2$$

3. Difference between two consecutive errors:

$$YDIFR = U(I) - U(I-1)$$

4. sum of squares of the consecutive errors:

$$DIFQS = \sum_{I=2}^{N} (U(I) - U(I-1))^2$$

5. Durbin-Watson - D-Statistics:

$$D = DIFQS/UISQS$$

...

APPENDIX 6

COST ESTIMATION OF ONE FLOWMETER THAT WAS FABRICATED IN THE LAB.

Total cost of Aluminium rod, brass pipes and brass plates	Rs.5.00
Cost of pyrex glass tube of 1 inch size	Rs.4.00
Cost of rubber corks	Rs.2.00
Approximate labour cost	Rs.10.00
Total:	Rs.21.00

Present rates

Aluminium rods	Rs.9.00/Kg.
Brass pipe and rod	Rs.20.00/Kg.
Pyrex glass tube (1 inch size)	Rs. 4.00/Kg.

...

APPENDIX 7

CALIBRATION OF THE ROTAMETER

The rotameter which was used as a means to indicate the flow rate in the present flowmeter experiments was re-calibrated before use. The observations of the rotameter calibration showed a linear behavior. A straight line was fit to the data with the least squares method. Tests were made for 95% confidence limits to delete the outliers if any, from the least squares computations. However, no outlier was found to exist. The experimental data alongwith the computer program is given below on the next page.

The final form of the least squares fit was

$$HT = 8.5590(Q) - 0.6224$$

$$\text{Variance} = 0.0306$$

where Q = liquid flowrate in liters/min.

HT = reading of float in cm.

$$\text{Variance} = \frac{\text{Residual sum of squares}}{\text{Degree of freedom}}$$

HT	Q	HT	Q
1.9	0.3040	2.9	0.4528
4.0	0.5764	6.0	0.7819
8.0	0.9967	9.0	1.1141
10.0	1.2192	12.0	1.4564
14.0	1.6783	16.0	1.9113
18.0	2.1497	20.0	2.3949
22.0	2.6519	24.0	2.8841
25.0	3.0243	25.2	3.0270
25.3	3.0490	25.5	3.0713
18.0	2.1470		

...

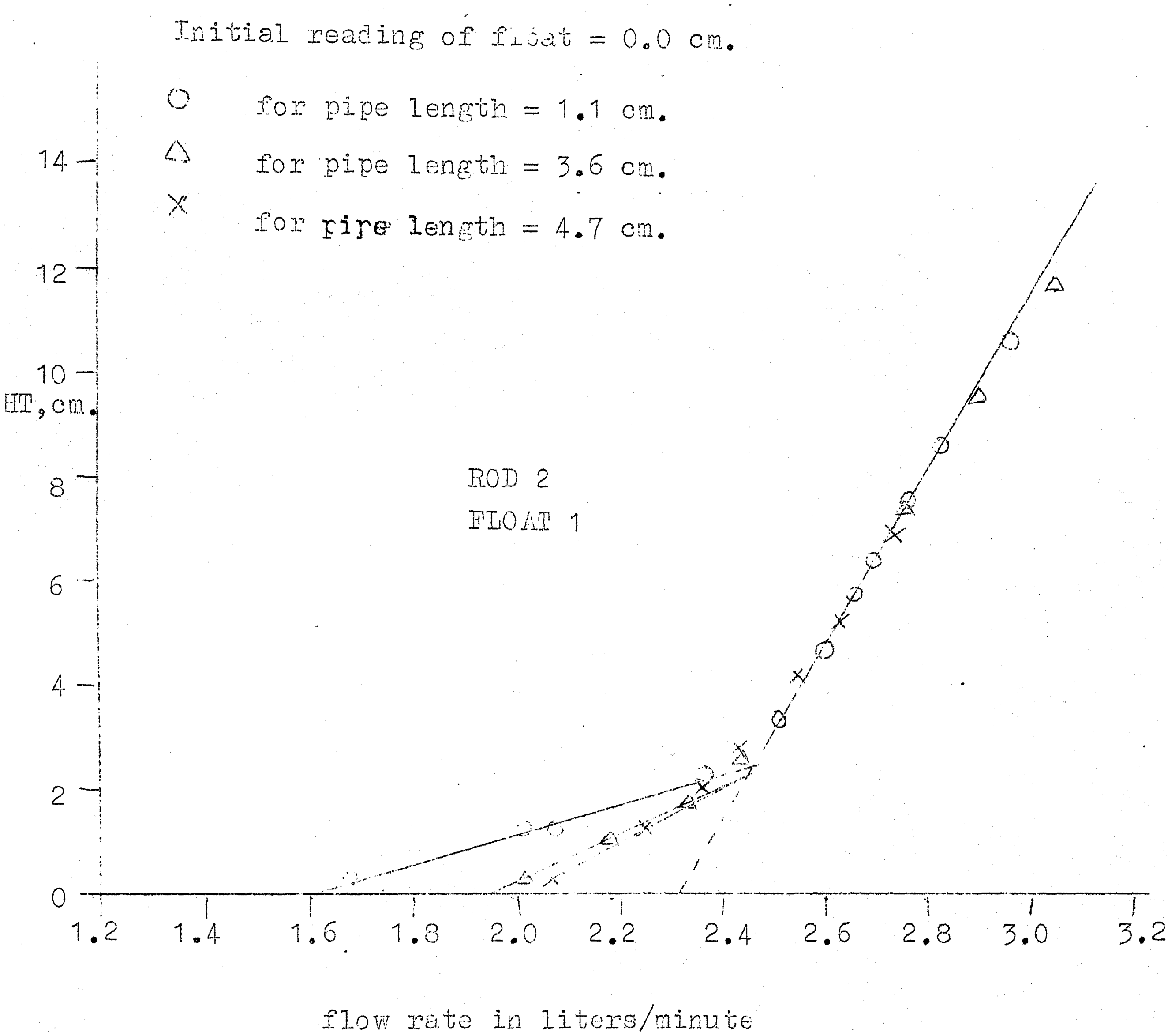

FIGURE 9: EFFECT OF PIPE SUPPORT LENGTH

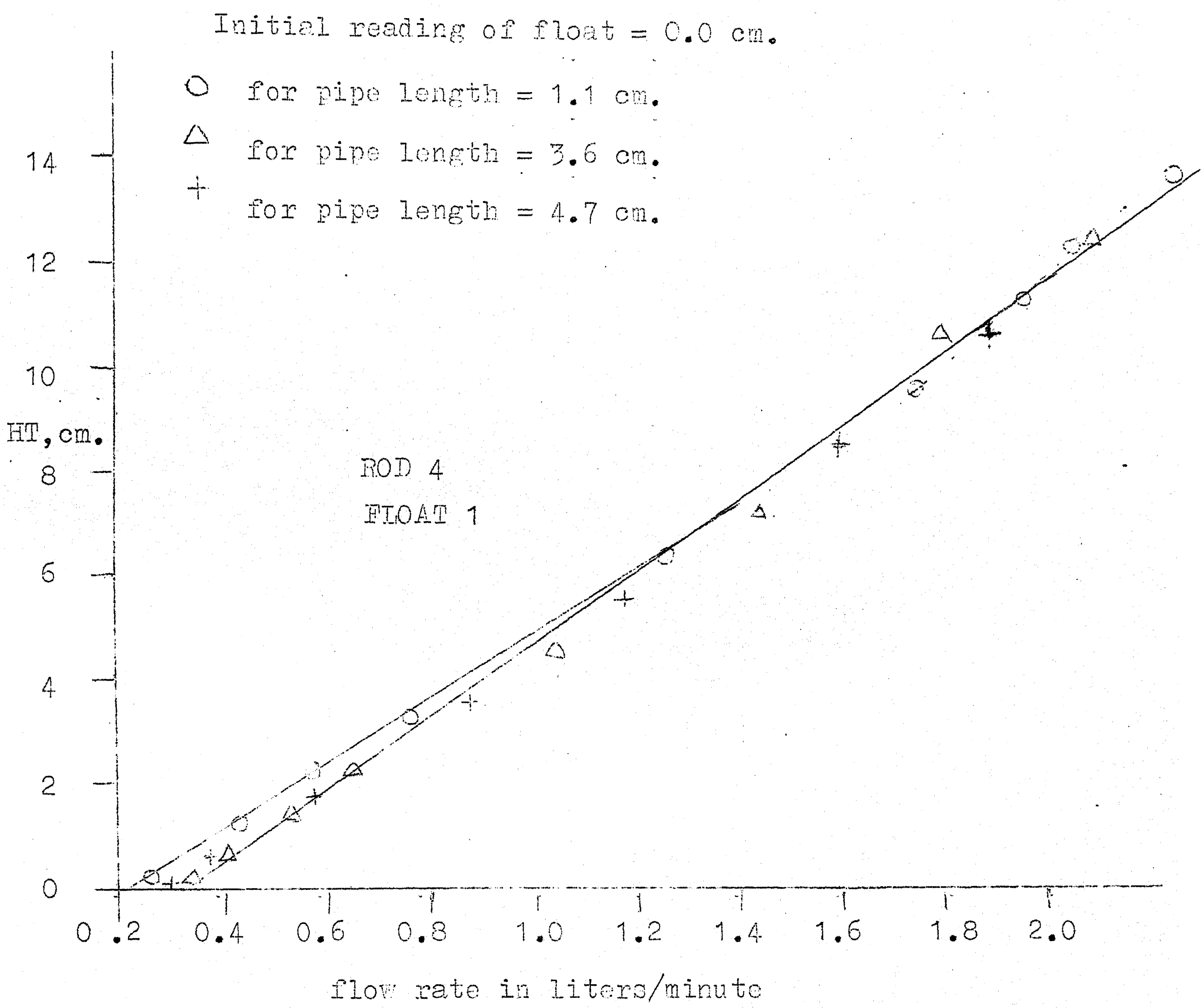

FIGURE 10: EFFECT OF PIPE SUPPORT LENGTH

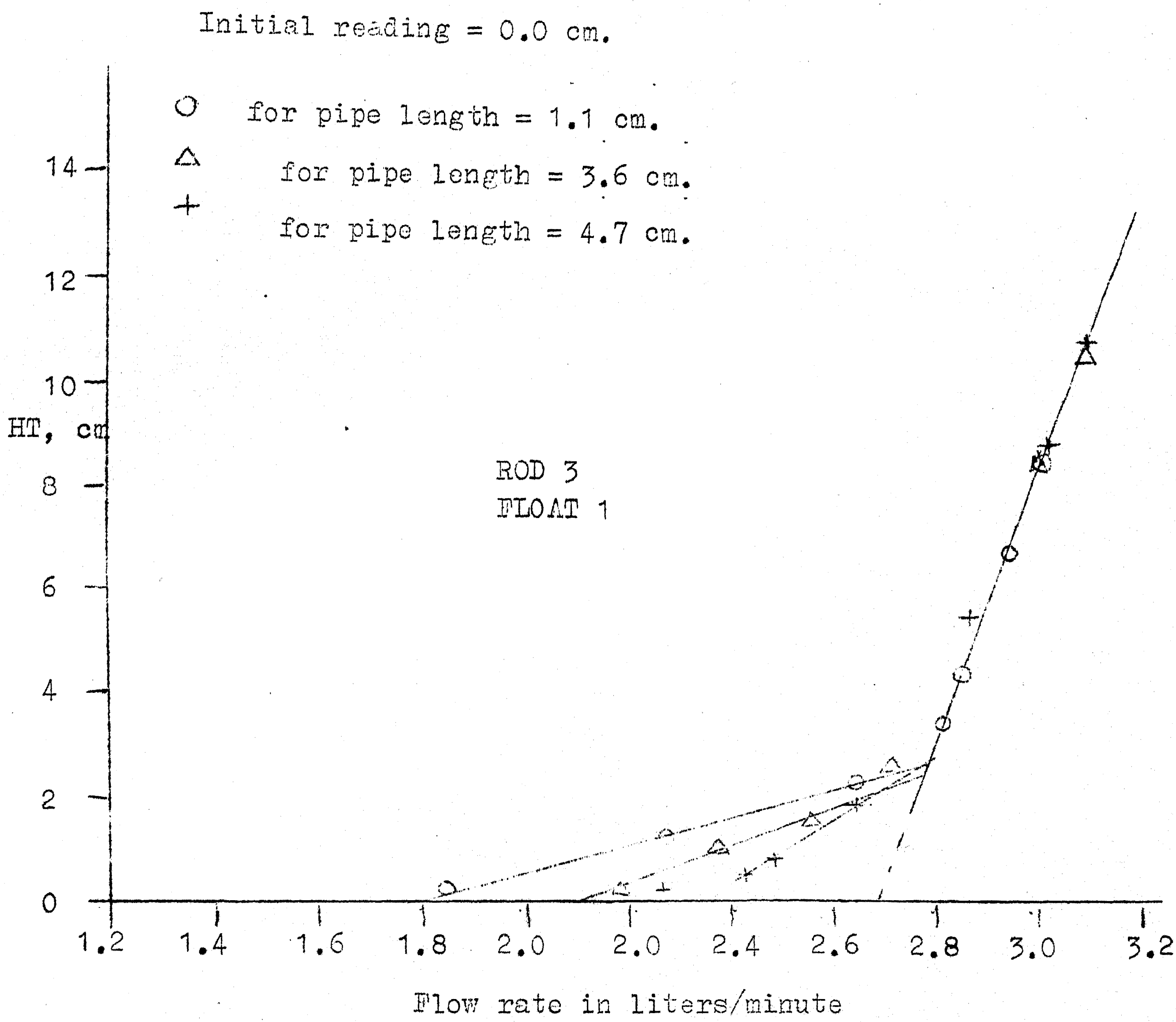

FIGURE 11: EFFECT OF PIPE SUPPORT LENGTH

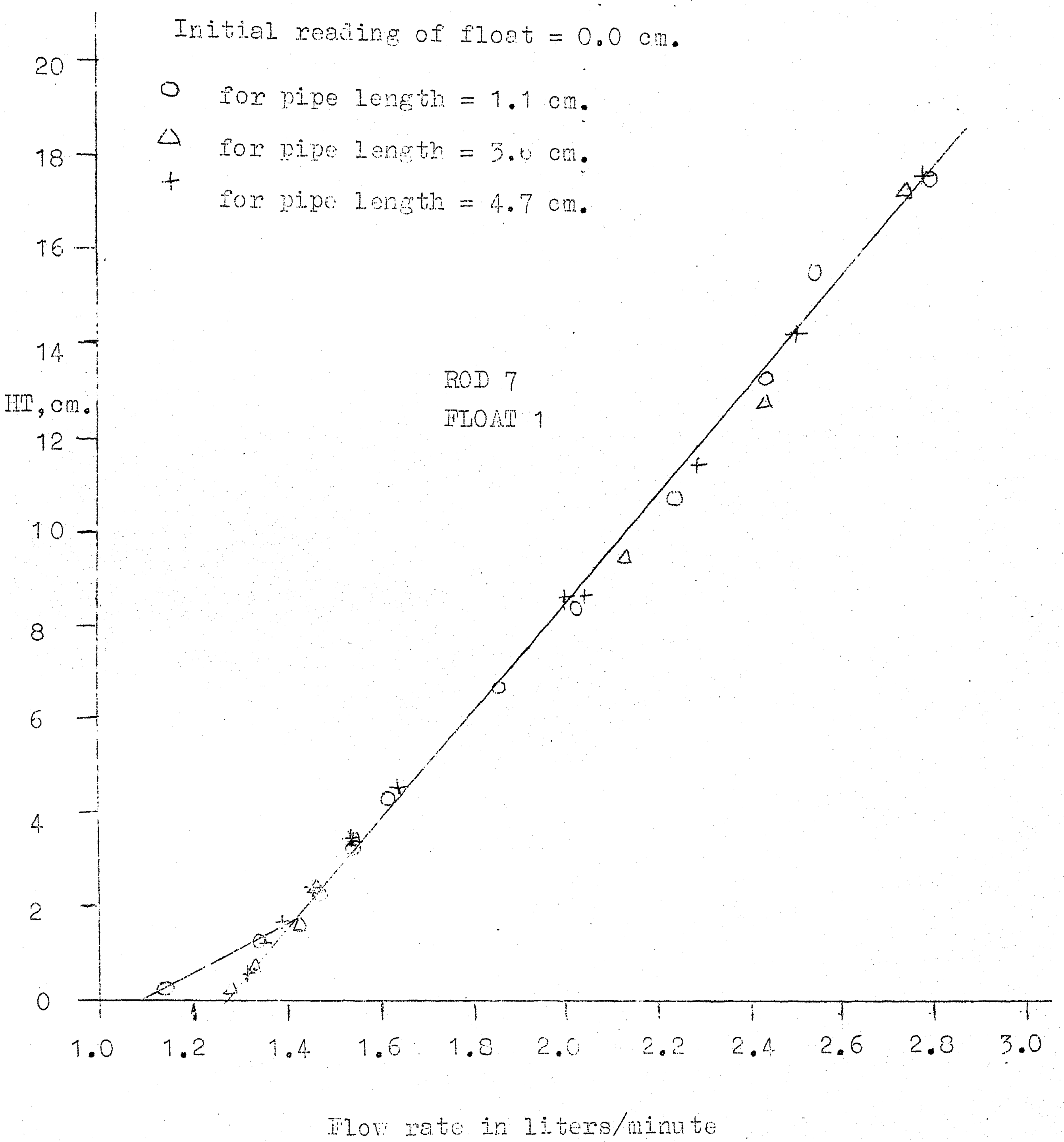

FIGURE 12: EFFECT OF PIPE SUPPORT LENGTH

```
C
C     THIS PROGRAM IS OF MULTIPLE-LINEAR-REGRESSION
C
C     A1=TOP DIA. OF TAPER ROD,INCH.
C     C1=BOTTOM DIA. OF ROD,INCH.
C     D1= INSIDE DIA. OF FLOAT,INCH.
C     D2= ORFICE DIA. OF FLOAT, INCH.
C     D3' =DIA.OF TAPER ROD CORRESPONDING TO HT, INCH.
C     H1= LENGTH OF FLOAT, INCH.
C     H2=LENGTH TAPERED ROD,CM.
C     H3'ORFICE THICKNESS, INCH.
C     G=ECCL. DUE TO GRAVITY,CM/SEC.-SEC.
C     FLOW=FLOW RATE, L/MIN.
C     HT=SCALE READING OF FLOAT, CM.
C     DENS=DENSITY OF FLOAT,G/CC.
C     DENW=DENSITY OF WATER,GM./CC.
C     MM=TOTAL NO. OF IND. VARIABLES
C     M1=TOTAL NO. OF VARIABLES
C     M=DEGREE OF POLYNOMIAL
C     N=TOTAL NO. OF OBSERVATIONS
C     XY(J,M1)'=DEPENDENT VARIABLE
      DIMENSION XY(300,8)
      MM=7
      J=0
      G=981.
      D=2.52
      DENW=.995
      U=.925
      DO 7 JN=1,7
      READ(5,101)N5,NN,C1,A1,H2
 101  FORMAT(2I2,2F6.3,F6.2)
      DO 1 JM=1,NN
      READ(5,200)D1,D2,H1,WS,DENS,H3
 200  FORMAT(F4.2,2F5.3,F6.4,2F5.3)
      N=N5
      R=(WS*G*(DENS-DENW))/DENS
      FO=U/SQRT(DENW*R)
      TANA=2.54*(C1-A1)/(2.*H2)
      DO 12 I=1,N
      READ(5,300)HT,FLOW
 300  FORMAT(F5.1,F7.4)
      D3=C1-(C1-A1)*(HT-.8)/H2
      OOP =2.54*(D2-D3)/D
      HOP =(100.*FLOW)/(6.*D)*SQRT(DENW*DENS/(WS*G*(DENS-DENW)))
      J=J+1
      XY(J,1)=HOP
      XY(J,2)=2.54*H3/D
      XY(J,3)=2.54*H1/D
      XY(J,4)=2.54*D1/D
      XY(J,5)=TANA
      XY(J,6)=FO
```

```
      XY(J,7)=2.54*C1/D
      XY(J,8)=OOP
12    CONTINUE
1     CONTINUE
7     CONTINUE
      INDEX=-2
      DO 4 I=1,3
      INDEX=INDEX+1
      CALL MLTRE(XY,J,MM,INDEX)
4     CONTINUE
      STOP
      END
      SUBROUTINE MLTRE(XY,N,MM,INDEX)
      DIMENSIONX(400,8),XY(400,8),SX(8),G(8,8),B(8),YG(8),VCOVM(8,8),
     1SCORM(8,8),YEST(300),T(8),U(300),ASCOR(8,8),C(8,8)
      TK=MM
      M1=MM+1
      ITER=M1
      IF(INDEX)224,555,204
204   DO255J=1,MM
      DO255I=1,N
255   X(I,J)=XY(I,J)
      DO256I=1,N
256   X(I,M1)=ALOG(XY(I,M1))
      WRITE(6,607)
607   FORMAT(/20X,82HINDEX POSITIVE , REGRESSION OF LOG DEPENDENT VARIAB
     1LEON GIVEN INDEPENDENTVARIABLES)
      GOTO565
224   DO260J=1,M1
      DO260I=1,N
      XYMT=XY(I,J)
      IF(XYMT)187,188,187
188   X(I,J)=0.
      GOTO260
187   X(I,J)=ALOG(XYMT)
260   CONTINUE
      WRITE(6,605)
605   FORMAT(/20X,56HINDEX NEGATIVE, REGRESSION ON LOGARITHMS OF ALLVARI
     1ABLES/)
      GOTO565
555   DO575J=1,M1
      DO575I=1,N
      X(I,J)=XY(I,J)
575   CONTINUE
      WRITE(6,606)
606   FORMAT(/20X,41HINDEX ZERO, REGRESSION ON GIVEN VARIABLES)
565   WRITE(6,80)ITER,N,MM
 80   FORMAT(/10X,16HNO. OF VARIABLES,I3/25X,12HOBSERVATIONS,I3/20X,14HI
     1ND. VARIABLES,I2/)
      AA=0.
      D=0.
      DO14J=1,M1
      DO15I=1,M1
      G(J,I)=0.
      VCOVM(J,I)=0.
      SCORM(I,J)=0.
```

```
 15   CONTINUE
      B(J)=0.
      SX(J)=0.
      YG(J)=0.
 14   CONTINUE
      TN=FLOAT(N)
      DO20J=1,M1
      DO20I=1,N
 20   SX(J)=SX(J)+X(I,J)
      WRITE(6,900)
900   FORMAT(/10X,32HSX=SUM OF INDIVIDUAL VAR. VALUES/)
      DO901J=1,M1
901   WRITE(6,19)J,SX(J)
 19    FORMAT(/20X,3HSX(,I1,2H)=,F15.6)
      DO11K=1,M1
      DO11J=K,M1
      DO11I=1,N
 11   G(K,J)=G(K,J)+X(I,K)*X(I,J)
      DO313K=1,M1
      DO313J=K,M1
313   G(K,J)=G(K,J)-((SX(K)*SX(J))/TN)
      DO191J=2,M1
      K=J-1
      DO191I=1,K
191   G(J,I)=G(I,J)+0.
      WRITE(6,151)
151   FORMAT(/6X,54HMATRIX OF SUM OF SQUARES AND CROSS PRODUCTS FROM MEANS/)
     1NS/)
      WRITE(6,194)((G(I,J),J=1,MM),I=1,MM)
194   FORMAT(/6X,7F15.6)
      DO120I=1,M1
      DO120J=1,M1
      SCORM(I,J)=G(I,J)/SQRT(G(I,I)*G(J,J))
 120   ASCOR(I,J)=SCORM(I,J)
      WRITE(6,122)
 122 FORMAT(/20X,25HSIMPLE CORRELATION MATRIX/)
      WRITE(6,124)((SCORM(I,J),J=1,M1),I=1,M1)
124   FORMAT(/6X,8F12.6)
      DO55I=1,M1
      YG(I)=G(I,M1)
 55   WRITE(6,60)I,YG(I)
 60   FORMAT(/20X,3HYG(,I1,2H)=,F15.6)
      CALL MATIN(G,MM,DETER)
      WRITE(6,113)
113   FORMAT(/30X,15HINVERTED MATRIX/)
      WRITE(6,114)((G(I,J),J=1,MM),I=1,MM)
114   FORMAT(/6X,7F15.6 )
      DO42J=1,MM
      DO41I=1,MM
 41   B(J)=B(J)+G(J,I)*YG(I)
      D=D+B(J)*YG(J)
 42   CONTINUE
      R=SQRT(D/YG(M1))
      RSS=YG(M1)-D
      DF=TN-TK-1.
      VEROR=RSS/DF
```

```
      WRITE(6,64)YG(M1),VEROR,DF
64    FORMAT(/6X,12HSQS. SUMMED=,F12.6/6X,21HERROR=RESIDUAL SS/DF=,
     1F12.6/10X,9HDF FOR T=,F3.0)
      WRITE(6,61)
61    FORMAT(/20X,1HI,5X,4HB(I),5X,16HST. ERROR OF B,S,4X,1HT)
      DO68I=1,MM
      DO66J=1,MM
66    VCOVM(I,J)=G(I,J)*VEROR
      AA=AA+B(I)*SX(I)
      DRB=SQRT(VCOVM(I,I))
      T(I)=B(I)/DRB
      WRITE(6,81)I,B(I),DRB,T(I)
 81   FORMAT(17X,I4,1X,E11.5,1X,F15.7,1X,F13.5)
 68   CONTINUE
      WRITE(6,71)
71    FORMAT(/20X,26HVARIANCE COVARIANCE MATRIX/)
      WRITE(6,72)((VCOVM(I,J),J=1,MM),I=1,MM)
  72  FORMAT(/10X,7F15.6)
      AA=(SX(M1)-AA)/TN
      RSQ=R*R
      F=(RSQ*DF)/((1.-RSQ)*TK)
      KM1=TK
      NMK=DF
      WRITE(6,77)D,RSS,AA,R,F,NMK
 77   FORMAT(/20X,18HEXPL. SUM OF SQS.=,F15.6/20X,21HRESIDUAL SUM OF SQS
     1.=,F15.6/20X,5HB(0)=,F15.6/20X,2HR=,F15.6/20X,2HF=,F15.6/20X,3HDF=
     1,I4)
      WRITE(6,300)
 300  FORMAT(1H0,45X,26HANALYSIS OF VARIANCE TABLE//5X,19HSOURCE OF VARI
     1ATION,3X,2HDF,3X,11HSUM OF SQS.,3X,12HCALCULATED-F,3X,6HREMARK)
      WRITE(6,302)KM1,D,F
 302  FORMAT(1H0,10X,10HREGRESSION,6X,I3,F11.6,2X,F15.6)
      WRITE(6,304)NMK,RSS
304   FORMAT(1H0,12X,8HRESIDUAL,6X,I3,F11.6)
      N1=N-1
      WRITE(6,306)N1,YG(M1)
306   FORMAT(1H0,15X,5HTOTAL,6X,I3,F11.6)
      WRITE(6,182)
182   FORMAT(1H0)
      YESTT=0.
      UISQS=0.
      DO 159 I=1,N
      DO 150 J=1,MM
      YESTT=YESTT+B(J)*X(I,J)
150   CONTINUE
      YESTT=YESTT+AA
      XIMI=X(I,M1)
      UI=XIMI-YESTT
      UISQ=UI*UI
      UISQS=UISQS+UISQ
      YEST(I)=YESTT
      U(I)=UI
      YESTT=0.
159   CONTINUE
      DIFQS=0.
      DO 169 I=2,N
```

```
      YDIFR=U(I)-U(I-1)
      YDIFQ=YDIFR*YDIFR
      DIFQS=DIFQS+YDIFQ
 169  CONTINUE
C-----------DWDST=DURBIN-WATSON D-STATISTICS----------------
      DWDST=DIFQS/UISQS
      WRITE(6,179)DWDST,N,MM,UISOS
 179 FORMAT(1H0,12X,27HDURBIN WATSON D-STATISTICS=,F15.6/15X,13HOBSERVA
    1TIONS=,I4/12X,22HEXPLANATORY VARIABLES=,I5/12X,6HUISOS=,F15.6//)
      DO 181 J=1,M1
      DO 181 I=1,N
      X(I,J)=0.0
 181  CONTINUE
C 988 READ4,NODTA
C     IF(NODTA)518,183,1
 184  FORMAT(5X,F8.3,F7.3,F8.3,F7.3,F8.3,F7.3,F8.3)
      RETURN
      END
      SUBROUTINE MATIN(A,N,DETER)
      DIMENSION IPIVO(8),A(8,8),INDEX(8,2),PIVOT(8)
      ABSF(X)=ABS(X)
C      INITIALIZATICN
 10   DETER=1.
      M=1
  15  DO20J=1,N
 20   IPIVO(J)=0
  30  DO550I=1,N
C
C    SEARCH FOR PIVIT ELEMENT
C
   40 AMAX=0.
   45 DO105J=1,N
 50   IF(IPIVO(J)-1)60,105,60
   60  DO100K=1,N
  70  IF(IPIVO(K)-1)80,100,740
   80 IF(ABSF(AMAX)-ABSF(A(J,K)))85,100,100
   85 IRCW=J
 90   ICOLM=K
   95 AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
 110  IPIVO(ICOLM)=IPIVO(ICOLM)+1
 130  IF(IROW-ICOLM)140,260,140
 140  DETER=-DETER
  150 DO200L=1,N
  160 SWAP=A(IROW,L)
 170  A(IROW,L)=A(ICOLM,L)
 200  A(ICOLM,L)=SWAP
  260 INDEX(I,1)=IROW
 270  INDEX(I,2)=ICOLM
 310  PIVOT(I)=A(ICOLM,ICOLM)
 320  DETER=DETER*PIVOT(I)
C
C      DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
 330  A(ICOLM,ICOLM)=1.
```

```
  340 DO 350 L=1,N
 350   A(ICOLM,L)=A(ICOLM,L)/PIVOT(I)
C
C        REDUCE NON-PIVOT ROWS
C
  380 DO550L1=1,N
 390   IF(L1-ICOLM)400,550,400
 400   T=A(L1,ICOLM)
 420   A(L1,ICOLM)=0.
 430   DO 450 L=1,N
 450   A(L1,L)=A(L1,L)-A(ICOLM,L)*T
  550 CONTINUE
C
C       INTERCHANGE COLUMNS
C
 600   DO 710 I=1,N
 610   L=N+1-I
 620   IF(INDEX(L,1)-INDEX(L,2))630,710,630
 630   JROW=INDEX(L,1)
 640   JCOLM=INDEX(L,2)
 650   DO 705 K=1,N
 660   SWAP=A(K,JROW)
 670   A(K,JROW)=A(K,JCOLM )
 700   A(K,JCOLM)=SWAP
 705   CONTINUE
 710   CONTINUE
 740      CONTINUE
       RETURN
       END
```
CEETIY

```
// JOB
// FOR NAME
*NON PROCESS PROGRAM
*IOCS(CARD,TYPEWRITER)
C
C      THIS PROGRAM IS OF ST. LINE FIT BY LEAST SQS.
C       95 PERCENT CONFIDENCE LIMIT IS TESTED
C      THIS PROGRAM WAS RUN ON IBM 1800
C
C      N=NO. OF OBSERVATIONS
       REAL M
       DIMENSION H(20),Q(20),QE(20),ERROR(20),QE1(20),QE2(20),K(20),
      1PEROR(20)
       FO=0.
       TANA=0.
       KO=1
       KP=2
       N=19
       DO 1 I=1,N
       READ(KP,111)H(I),Q(I)
 111   FORMAT(F4.1,1X,F6.4)
 1     CONTINUE
       II=1
       IF(II-1)8,11,8
  8    KL=0
       DO 9 I=1,N
       DO 10 J=1,L
       IF(I-K(J))10,9,10
  10   CONTINUE
       KL=KL+1
       H(KL) =H(I)
       Q(KL) =Q(I)
  9    CONTINUE
       N=KL
  11   SUMH =0.
       SUMQ=0.
       SUMHH=0.
       SUMHQ=0.
       DO 2 I=1,N
       SUMH=SUMH+H(I)
       SUMQ=SUMQ+Q(I)
       SUMHQ=SUMHQ+H(I)*Q(I)
       SUMHH=SUMHH+H(I)*H(I)
  2    CONTINUE
       PN=N
       M=(SUMH*SUMQ-PN*SUMHQ)/(SUMH*SUMH-PN*SUMHH)
       C=(1./PN)*(SUMQ-M*SUMH)
       SUME=0.
       DO 3 I=1,N
       QE(I)=M*H(I)+C
```

```
      ERROR(I)=Q(I)-QE(I)
      SUME=SUME+ERROR(I)**2
      PEROR(I)=ERROR(I)*100./Q(I)
      CONTINUE
      SIGMA=SQRT(SUME/FLOAT(N-1))
      VER=SUME/FLOAT(N-1)
      C4=C-1.96*SIGMA
      C2=C+1.96*SIGMA
      L=0
      DO 5 I=1,N
      QE1(I)=M*H(I)+C4
      QE2(I)=M*H(I)+C2
      IF(Q(I)-QE2(I))31,31,30
 31   IF(Q(I)-QE1(I))30,5,5
 30   WRITE(KO,201)I,Q(I),H(I)
 201  FORMAT(I7,2F12.4)
      L=L+1
      K(L)=I
  5   CONTINUE
      IF(L)8,6,8
 6    WRITE(KO,301)
 301  FORMAT(5X,38HNO VALUE OUTSIDE 95PERCENT SIGMA LIMIT)
      WRITE(KO,100)C,M,SIGMA,VER
 100  FORMAT(//8X,2HC=,F8.4, 5X,2HM=,F8.4, 5X,5HSIGMA,F8.4,
     15X,3HVER,F8.4//)
      DO 7 I=1,N
      WRITE(KO,91)H(I),Q(I),QE(I),PEROR(I)
 91   FORMAT(4F15.4)
 7    CONTINUE
      CALL EXIT
       END
// XEQ NAME
* CCEND
```